Geographical Segregation, Misallocation and Productivity in Apartheid South Africa Manufacturing:

How the Railways of Separation Became Tracks to Integration

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Abstract

This paper studies the economic consequences of a state infrastructure project designed to support institutionalized segregation. I construct a novel panel linking newly digitized regional manufacturing censuses to the staggered modernization of South Africa's railway network from 1970 to 1985. A Callaway-Sant'Ana difference-in-differences design provides causal estimates of the impact of the upgrades on manufacturing productivity. I find that the upgrades, which lowered transport costs for a racially segregated labour force, caused a large increase in aggregate manufacturing productivity. This productivity gain arose not from improvements in firm-level efficiency, but almost entirely from enhanced allocative efficiency, as the upgrades facilitated a better spatial matching of labour to firms. The results show how infrastructure investment can powerfully reduce misallocation, providing a stark example of an instrument of segregation inadvertently fostering economic integration.

- **2606 Word count**

1 Introduction

The economic history of South Africa in the second half of the twentieth century presents a profound paradox. On one hand, the apartheid state operated as a developmental engine for the white minority, driving rapid industrialisation and ambitious infrastructure projects, including the modernisation of the national railway network (Lin and Si'ao, 2025; Feinstein, 2005). On the other, it was a machine of spatial distortion, enforcing a policy of "Grand Apartheid" that forcibly separated the Black labour force from the white industrial centres where they were employed (Davies, 1981).

To reconcile these conflicting objectives—segregation and growth—the state relied on a massive transport network. The state-owned railway system became the logistical backbone of apartheid, tasked with moving millions of Black workers daily between distant, segregated townships and urban factories. Paradoxically, the very infrastructure designed to make segregation viable became a force for economic integration.

This paper investigates the economic consequences of the state's large-scale modernisation of the railway network between 1970 and 1985. Using a novel dataset constructed from newly-digitised regional manufacturing censuses and geocoded historical railway maps, I estimate the causal impact of upgrading rail lines from steam to diesel and electric traction. Exploiting the staggered rollout of these upgrades in a difference-in-differences framework, I find that railway modernisation led to a large and statistically significant increase in aggregate manufacturing productivity in connected districts.

Crucially, a decomposition of this growth reveals that it was driven almost entirely by improvements in Allocative Efficiency (AE), rather than firm-level technical efficiency (TFPR). By reducing the effective cost of the "transport tax" imposed on Black workers, the upgrades facilitated a reduction in *de facto* segregation, allowing for a more efficient spatial allocation of labour. This indicates that the primary economic impact of the railway upgrades was not technological, but re-allocative; they helped correct the severe misallocation of labour, a defining feature of the apartheid economy.

This paper contributes to three strands of literature. First, it adds to the research on resource misallocation (Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009; Hornbeck and Rotemberg, 2024). While foundational work demonstrates the scale of potential TFP gains from eliminating misallocation, this study provides causal evidence that large-scale infrastructure investment can act as a specific tool for improving allocative efficiency by reducing labour market frictions. Second, it contributes to the literature on infrastructure and growth (Donaldson and Hornbeck, 2016; Jedwab and Moradi, 2016), demonstrating that in distorted economies, infrastructure's primary value may lie in unwinding institutional inefficiencies rather than lowering freight costs. Finally, it provides a unique test of Becker (1957)'s theory of discrimination, showing that market forces, when enabled by infrastructure, can undermine even state-enforced discrimination.

2 Historical Context: The Iron Spine of Apartheid

The spatial engineering of apartheid created a fundamental economic problem: how to fuel industrial centres with cheap labour while keeping that labour force residentially segregated and geographically distant. The legislative framework, anchored by the Group Areas Act of 1950, mandated strict residential segregation, displacing millions of Black South Africans to peripheral townships (Feinstein, 2005). However, the burgeoning manufacturing sector required a steady supply of labour, necessitating a transport system capable of internalising the externality of long-distance commuting.

2.1 The Economics of the Commute

The apartheid spatial geography was defined by a separation of the "white city" with production and white residence and the "black townships" for black residence. This separation imposed a transport tax on the black workforce, paid in both time and money. Commutes of 40 to 60 kilometers each way were common, such as the daily journey from Soweto to Johannesburg or Umlazi to Durban (Pirie, 1993).

The state-owned South African Railways (SAR) bridged this gap. Unlike road transport, which had high variable costs, rail offered economies of scale crucial for moving high volumes of low-wage commuters over long distances (Pienaar et al., 2012). Because the apartheid economy depended on keeping black wages low, workers could not absorb the full cost of these forced, lengthy commutes. The state therefore intervened with substantial subsidies to keep the workforce mobile (Baffi, 2014). Consequently, the railway became the primary artery of the apartheid labour economy. As shown in Figure A.1, Black passenger ridership surged during this period, even as white ridership declined in favour of private automobiles.

2.2 Technological Transition: Steam to Diesel and Electric

By the early 1970s, the aging steam-based network was effectively at capacity. To sustain the segregationist model, the state embarked on an ambitious modernisation programme. Between 1970 and 1985, the SAR transitioned from steam traction to more efficient diesel and electric locomotives (Basu, 2006; Arup, 2012).

This was not merely a technical upgrade; it was a strategic necessity to increase capacity and speed. Diesel and electric locomotives allowed for longer trains and faster turnaround times, significantly increasing the volume of labour that could be transported from peripheral townships to industrial cores (Arup, 2012). For example, the electrification of lines serving the Witwatersrand allowed for higher frequency schedules during peak hours, effectively expanding the labour catchment area for manufacturing firms. The scale of investment was immense, with the number of electric locomotives growing by 400% between 1969 and 1989.

This period of modernisation provides a unique quasi-experimental setting. The upgrades were rolled out geographically over time, creating variation in transport efficiency across manufacturing districts. Figures A.3 through A.4 depict this staggered progression. While intended to reinforce the political objective of spatial separation, these upgrades lowered the friction of distance, potentially altering the economic allocation of the workforce.

3 Data and Measurement

To analyse the impact of these upgrades, I construct a new panel dataset linking infrastructure improvements to district-level manufacturing outcomes. This involved a significant digitization effort to recover granular historical data.

3.1 Manufacturing Data Construction

I digitised the regional tables from the South African Manufacturing Censuses for 1970, 1980, and 1985. These documents record gross revenue, capital stock, wage bills, and intermediate input costs for 18 major industry groups across 250 magisterial districts.

A key challenge in constructing this panel was the shifting geography of apartheid. The creation of "Homelands" (Bantustans) in the 1970s led to the redrawing of district boundaries, creating a "Swiss cheese" map where certain areas were excised from official South African statistics (see Figure A.2). To address this, I harmonise district boundaries to their 1970 definitions. I digitised historical shapefiles for 1970, 1980, and 1985 and computed area-weighted crosswalks to reallocate data from the fragmented 1980/1985 districts back to the consistent 1970 parent districts. This methodology, following Hornbeck (2010) and Eckert et al. (2020), ensures that the unit of analysis remains stable over time, allowing for the tracking of productivity within a fixed geographic area.

Furthermore, industry classifications evolved between 1970 and 1985. To ensure temporal consistency, I re-aggregated the more detailed industry codes from the later censuses to match the broader 18-sector classification used in 1970 (see Appendix Table A.4). For each district-industry-year, I observe gross revenue (Y_{dit}), capital expenditure (K_{dit}), labour expenditure (L_{dit}), and materials (M_{dit}). This allows for the estimation of district-level production functions and the identification of input wedges.

3.2 Railway Data Digitization

I constructed the treatment variable by digitising and geocoding annual railway maps from the Department of Transport. These maps detail the specific rail segments upgraded from steam to diesel or electric power in each year. I overlay these historical maps onto the 1970 district boundaries to determine the treatment status of each district in each census year. A district is considered treated if its main railway line was upgraded to diesel or electric traction. As shown in Figure A.4, the rollout was progressive, providing sufficient variation for identification; by 1970 only 30 districts were upgraded, expanding significantly by 1985.

4 Theoretical Framework and Identification

The central hypothesis of this paper is that apartheid policies created friction in the labour market, preventing the efficient matching of workers to firms. To test this, I employ a standard framework for measuring resource misallocation.

4.1 Measuring Misallocation: The "Wedge" Approach

The theoretical framework relies on identifying distortions that drive a wedge between the marginal product of inputs and their marginal costs. Following Hsieh and Klenow (2009), I assume a Cobb-Douglas production function with constant returns to scale. In a frictionless, efficient market, a profit-maximizing firm will equate the marginal revenue product of an input (like labour) to its cost (the wage). Consequently, the output elasticity of an input should equal its share of total revenue.

However, if there are frictions, such as the high cost of transporting labour from a segregated township, the firm faces a cost higher than the wage. This drives a wedge between the marginal product and the observed cost. As shown in Figures A.5 and A.6, the data reveals significant positive wedges in the South African manufacturing sector. This indicates that inputs, particularly labour and capital, were underutilised relative to their efficiency.

To quantify the impact of rail upgrades, I estimate aggregate district productivity ($\mathscr{Pr}_d$), defined as total revenue net of input costs (Hornbeck and Rotemberg, 2024). I decompose the growth in aggregate productivity into two components:

1. **Revenue Total Factor Productivity (TFPR):** Gains arising from improvements in the technical efficiency of firms (e.g., better technology or management).
2. **Allocative Efficiency (AE):** Gains arising from the reallocation of inputs towards firms or sectors where their marginal revenue product exceeds their marginal cost.

The marginal effect of rail upgrades ($\mathcal{U}_d$) on aggregate productivity can be decomposed as:

$$\frac{\partial \ln \mathscr{Pr}_d}{\partial \mathcal{U}_d} = \underbrace{\phi_d \left[\frac{\partial \ln \mathscr{R}_d}{\partial \mathcal{U}_d} - \sum_{\nu} \alpha_d^{\nu} \frac{\partial \ln \varXi_d^{\nu}}{\partial \mathcal{U}_d} \right]}_{\text{TFPR}} + \underbrace{\phi_d \left[\sum_{\nu} (\alpha_d^{\nu} - \mathscr{s}_d^{\nu}) \frac{\partial \ln \varXi_d^{\nu}}{\partial \mathcal{U}_d} \right]}_{\text{Allocative Efficiency}} \tag{1}$$

where ϕ_d scales revenue to productivity, α_d^{ν} is the input elasticity derived from the production function estimation, and $\mathscr{s}_d^{\nu}$ is the observed revenue share. The AE term captures productivity growth explicitly driven by reducing the wedge $(\alpha_d^{\nu} - \mathscr{s}_d^{\nu})$. If $(\alpha_d^{\nu} > \mathscr{s}_d^{\nu})$, the input is underutilised. A positive shock that increases the use of this input (like a rail upgrade lowering the cost of access) will therefore increase Allocative Efficiency.

4.2 Empirical Strategy

I estimate the causal impact of railway upgrades using a staggered difference-in-differences (DiD) framework. Since the upgrades were rolled out in cohorts between 1970 and 1985, standard two-way fixed effects estimators may be biased due to heterogeneous treatment effects (Roth et al., 2023). Specifically, early adopters (high-capacity industrial corridors) likely have different treatment dynamics than late adopters.

I therefore employ the Callaway and Sant'Anna (2021) estimator, which compares districts that received an upgrade at time t to districts that had not yet received an upgrade, conditional on covariates. The estimation specification is:

$$y_{dt} = \theta_{dt} + \beta \mathcal{X}_d + \sum_g \delta_{gt} \mathbb{1}(G_d = g) + \epsilon_{dt} \tag{2}$$

where y_{dt} is the outcome (e.g., aggregate productivity, TFPR, AE) for district d in year t. The estimator conditions on pre-treatment covariates ($\mathcal{X}_d$), including population density, distance to the coast, and distance to mines, to satisfy the parallel trends assumption.

5 Results

5.1 Impact on Aggregate Productivity

The results indicate that railway upgrades had a substantial positive impact on the local manufacturing sector. Table A.1 and Figure A.7 show that rail upgrades are associated with a significant increase in manufacturing revenue. More importantly, Figure A.8 presents the event study coefficients for aggregate productivity. Districts connected to modernised rail lines experienced a statistically significant increase in aggregate productivity compared to unconnected districts.

To understand the source of this growth, I decompose the effect into its technical (TFPR) and allocative (AE) components. The decomposition in Figure A.8 and Table A.2 reveals a striking result: approximately 78% of the productivity gain is attributable to improvements in Allocative Efficiency, while the contribution of technical efficiency is smaller and statistically insignificant.

This suggests that the railway upgrades did not primarily boost growth by making individual factories more technologically efficient (e.g., by lowering freight costs for materials). Instead, the upgrades improved the *functioning of the market* itself. By enabling the movement of labour that was previously stuck in low-productivity locations (segregated townships or reserves), the infrastructure allowed firms to access a larger pool of labour and allowed workers to access higher-productivity employment. The rail lines acted as a mechanism for correcting the severe labour misallocation engineered by apartheid.

5.2 Mechanism: Reducing De Facto Segregation

To rigorously test the hypothesis that the productivity gains were driven by labour reallocation, I examine the link between rail upgrades and spatial segregation. Pirie (1993) and Baffi (2014) note that railways facilitated the movement of segregated labour into urban centres. If the mechanism is indeed the reduction of labour frictions, we should observe a change in the demographic composition of the industrial districts.

I construct a Location Quotient ($\mathcal{LQ}$) for the Black population in each urban industrial district. An increase in the $\mathcal{LQ}$ indicates that the Black population became more represented in that district relative to the national average.

Using the same difference-in-differences framework, I find that railway upgrades led to a statistically significant increase in the Black Location Quotient in treated districts (Figure A.9). This confirms that the modernised infrastructure successfully facilitated the movement of Black labour into industrial centres, effectively reducing *de facto* segregation even as *de jure* segregation remained in force.

Furthermore, Table A.3 and Figure A.10 show that when I re-estimate the impact on Allocative Efficiency while controlling for the change in segregation ($\mathcal{LQ}$), the treatment effect on AE diminishes significantly. This implies that the reduction in segregation is indeed the primary channel through which the railway upgrades improved economic efficiency.

6 Discussion and Conclusion

This paper has explored the unintended economic consequences of apartheid's spatial engineering. While the modernisation of the South African railway network was driven by the political imperative to maintain racial segregation, my analysis demonstrates that it paradoxically acted as a powerful force for economic integration.

The core result is that the transition from steam to diesel and electric traction caused a large and statistically significant increase in aggregate manufacturing productivity in connected districts. However, the decomposition of this growth challenges standard assumptions about infrastructure. The gains were driven not by technical improvements within firms (TFPR), but by a massive improvement in allocative efficiency. Reductions in transport costs reduced the "wedge" between the marginal product and cost of Black labour.

These findings resolve an apparent paradox in the literature. While Mariotti and van Zyl-Hermann (2014) and others document the rigid legal barriers of apartheid, this paper shows how infrastructure investment provided a mechanism to bypass spatial frictions. The upgraded rail lines lowered the "transport tax" on Black labour, reducing the friction of distance and allowing for a more efficient matching of workers to firms.

Broadly, this study contributes to development economics by demonstrating that in economies plagued by severe institutional frictions, whether legal, social, or geographic, infrastructure investment can generate substantial returns. These returns arise not just from lowering freight costs, but from unwinding misallocation and allowing the market to circumvent structural barriers. The South African experience serves as a potent example of how economic imperatives can erode political ideologies, as the very tracks laid to enforce separation ultimately accelerated the economic integration of the nation.

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A Figures and Tables

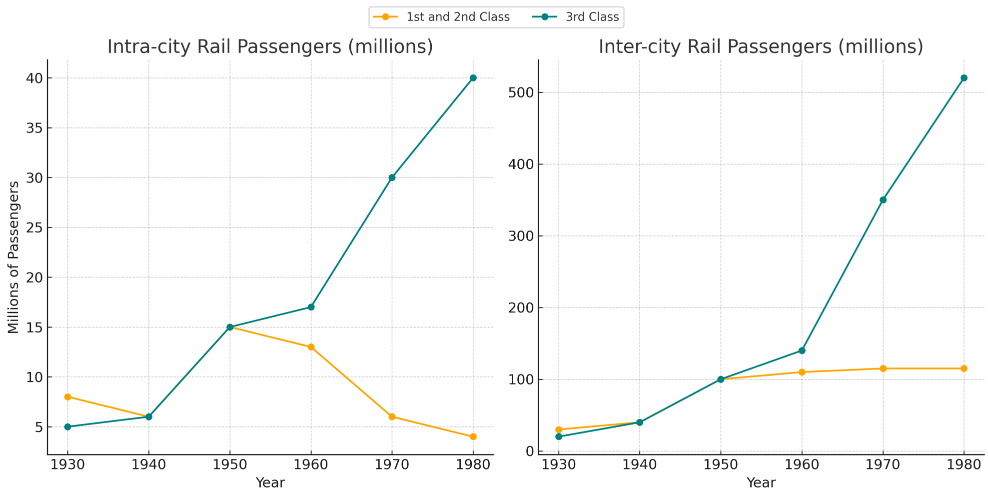


Figure A.1: Evolution of train use by Commuters

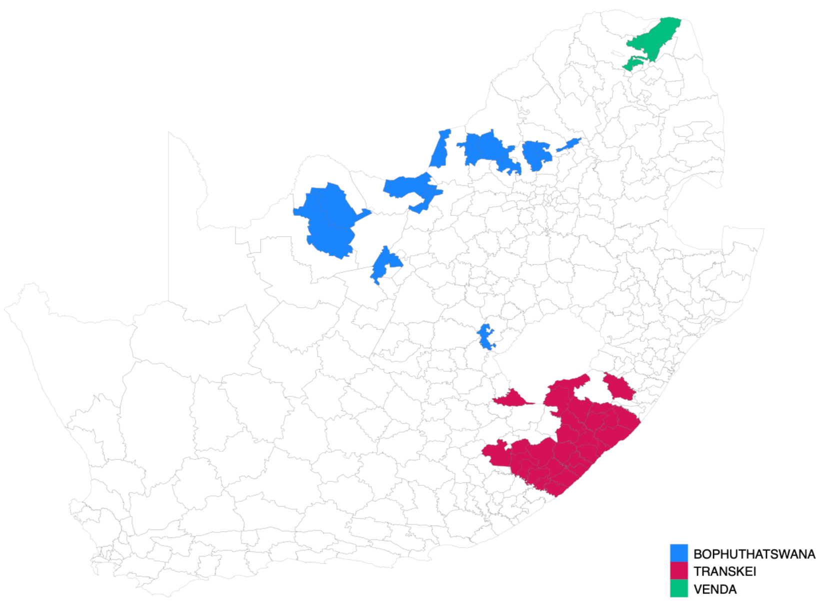
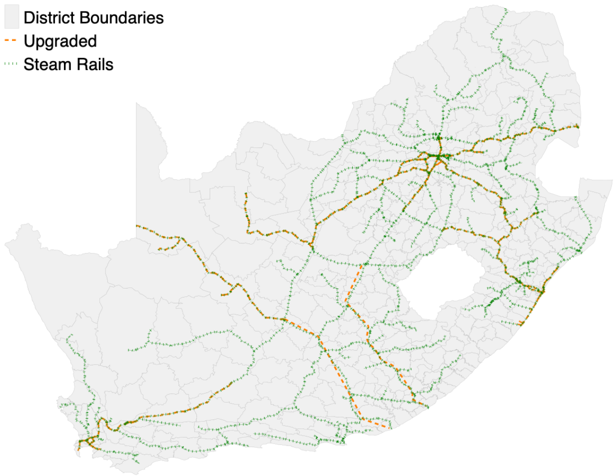
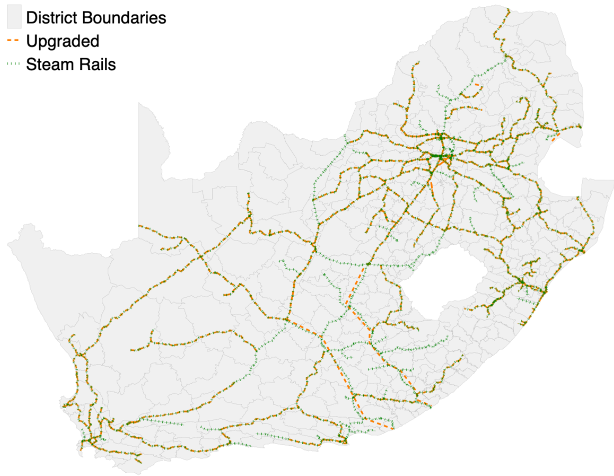


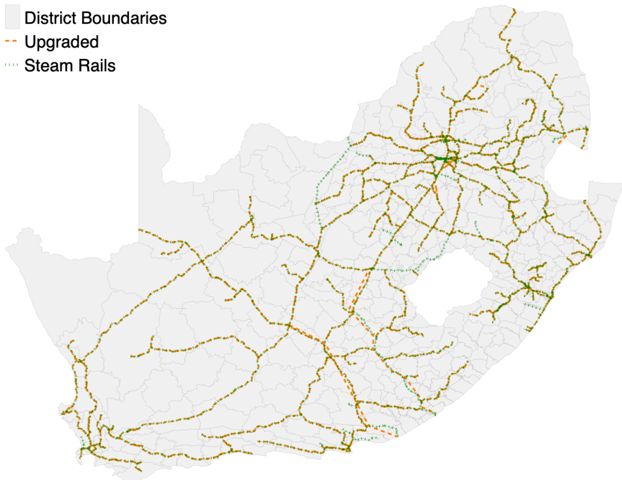
Figure A.2: Native homeland areas in 1980



(a) Map of rail upgrades up to 1970

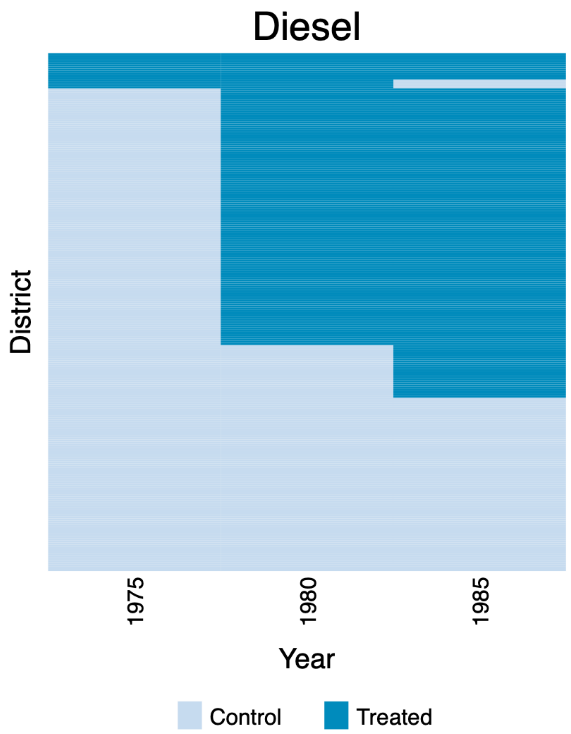


(b) Map of rail upgrades up to 1980

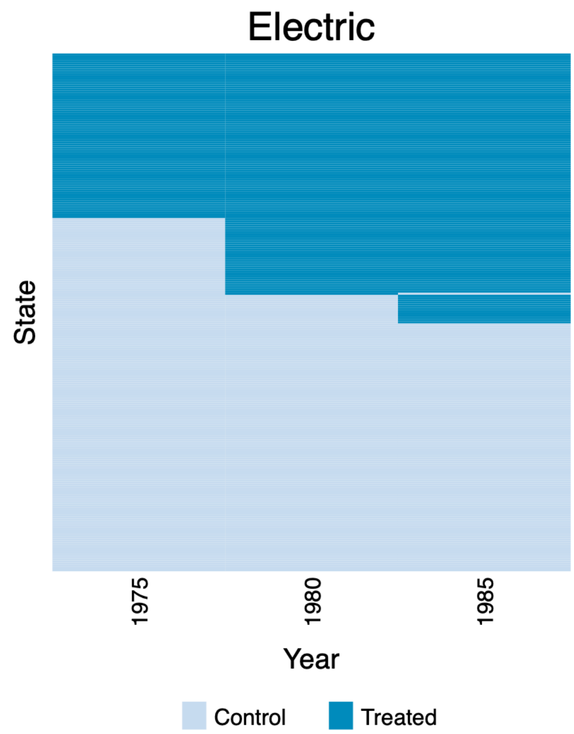


(c) Map of rail upgrades up to 1985

Figure A.3: Geocoded and digitised state of rail improvements



(a)



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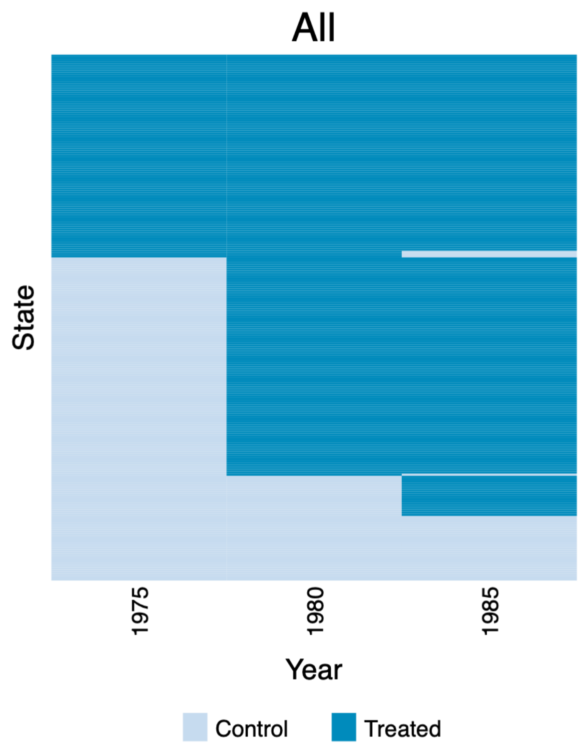
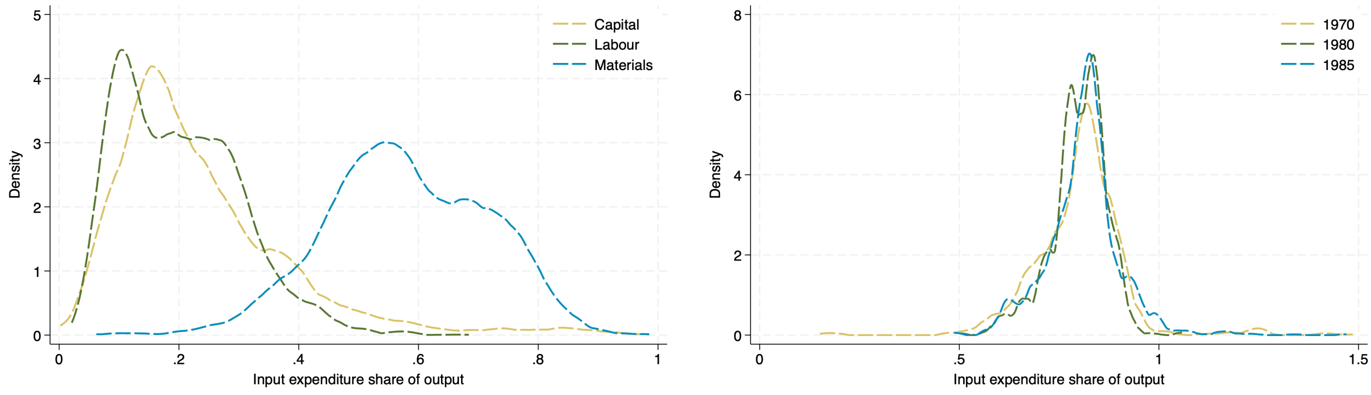


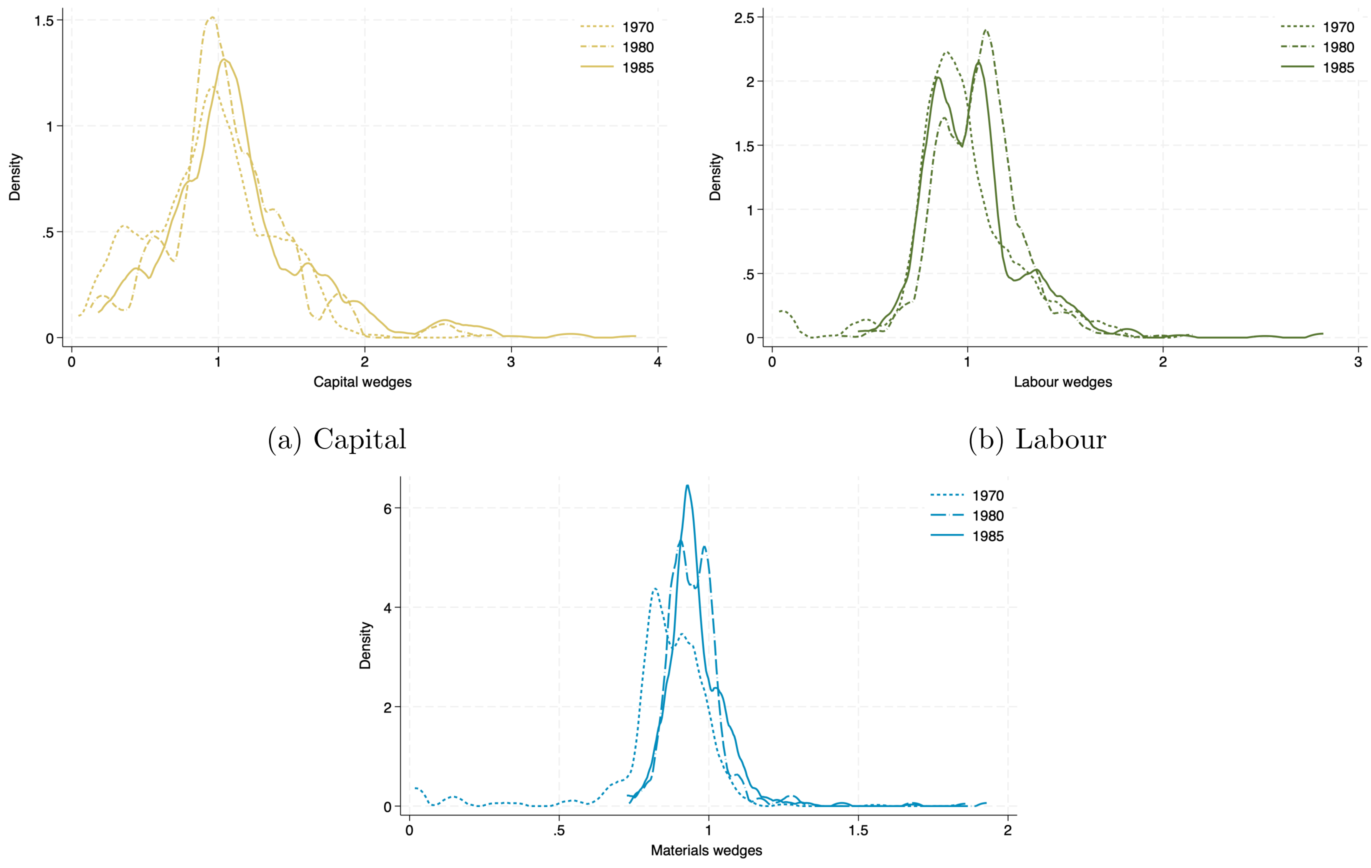
(c)

Figure A.4: Adoption of treatment by the districts over the census years



(a) (b)

Figure A.5: Distribution of input expenditure share of revenue



(a) Capital (b) Labour

(c) Materials

Figure A.6: Distribution of input wedges

Table A.1: Impact of Rail upgrades on output and inputs

	(1) Output	(2) Capital	(3) Materials	(4) Labour
ATT	3.85**	3.99**	3.93**	4.04**
	(1.38)	(1.36)	(1.39)	(1.37)
H0: Parallel trends				
Chi-square	0.1372	0.0277	0.0010	0.0128
P-Value	0.7110	0.8679	0.9750	0.9100

Notes: This table presents average treatment effects of rail upgrades on South Africa's manufacturing output and input expenditures over the period 1970-1985. The coefficients were estimated using the Callaway and Sant'Anna (2021) estimator with inverse probability weighting and "not yet" treated as the control group. There are three treated cohorts (1970, 1980 and 1985). Of these three, 1970 is always treated and therefore not included. Only districts that were previously connected to the rail network are included in the estimation. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses.

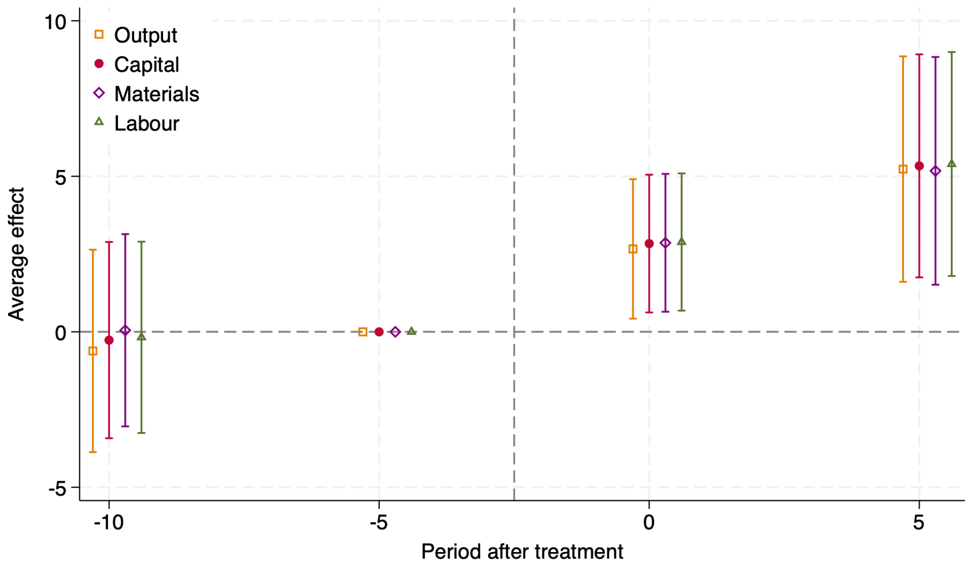


Figure A.7: Impact of Rail upgrades on output and inputs

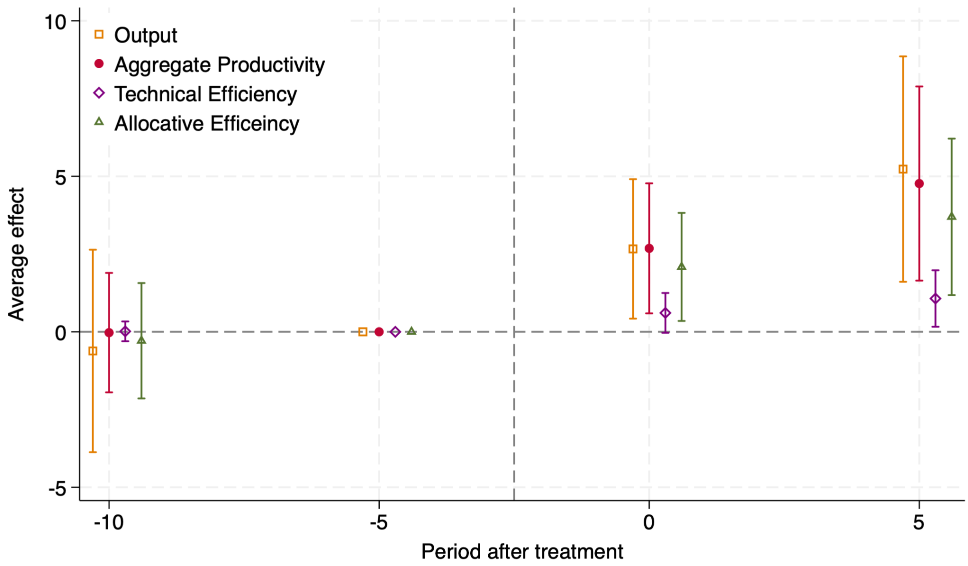


Figure A.8: Impact of Rail upgrades on productivity

Table A.2: Impact of Rail upgrades on productivity

	Log values			
	Output	Aggregate	TFPR	AE
Rail Upgrades	3.85**	3.64**	0.82*	2.83**
	(1.38)	(1.26)	(0.38)	(1.00)
H0: Parallel trends				
Chi-square	0.1372	0.0007	0.0091	0.0922
p-value	0.7110	0.9783	0.9240	0.7614

Notes: This table presents average treatment effects of rail upgrades on South Africa's manufacturing output and productivity over the period 1970-1985. The coefficients were estimated using the Callaway and Sant'Anna (2021) estimator with inverse probability weighting and "not yet" treated as the control group. Controls included for conditional parallel trends include population density, urban status, distance to coast and distance to mines. There are three treated cohorts (1970, 1980 and 1985). Of these three, 1970 is always treated and therefore not included. Only districts that were previously connected to the rail network are included in the estimation. The figure shows a decomposition of the effect on aggregate productivity into impact on TFPR and on AE. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses.

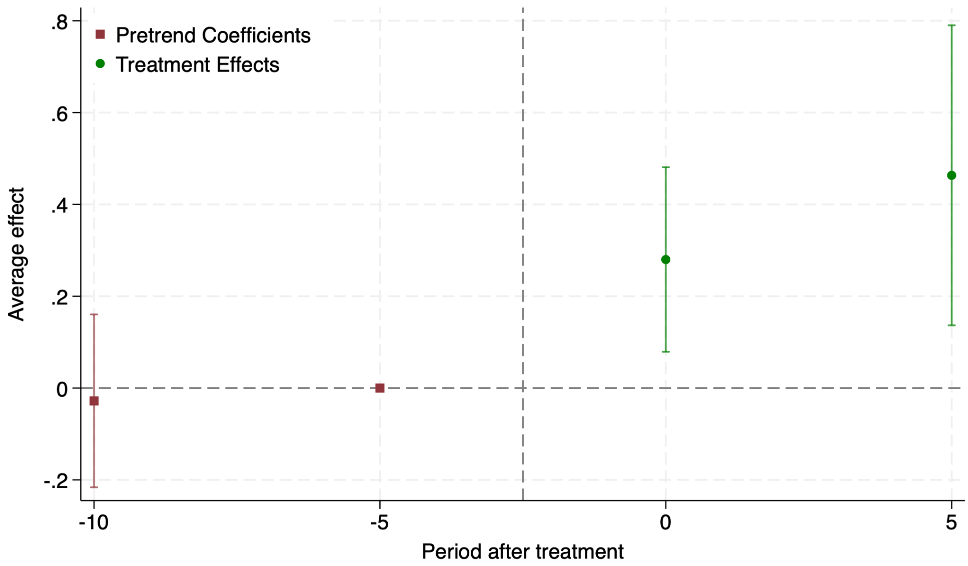


Figure A.9: Impact of Rail upgrades on Location Quotient

Table A.3: Effect of segregation on productivity and input distortions

	(1)	(2)	(3)	(4)	(5)
	AE	TFPR	Capital Wedges	Labour Wedges	Materials Wedges
$\mathcal{LQ}_{db}$	1.172**	0.066	-0.262	-0.081*	-0.057**
	(0.348)	(0.140)	(0.639)	(0.042)	(0.027)
district FE	Y	Y	Y	Y	Y
year FE	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y

Notes: This table presents results of a Fixed Effects regression of the productivity components (TFPR and AE) and input wedges on the segregation statistic ($\mathcal{LQ}_d^b$). Both year and district fixed effects are controlled for including controls for population density, urban status, distance to coast and distance to the nearest mine. Columns 1 and 2 present the marginal change in Allocative Efficiency and TFPR respectively, given a change in Location Quotient. Columns 2, 3 and 4 present the same effect for capital, labour and materials wedges. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.05$, Standard errors in parentheses.

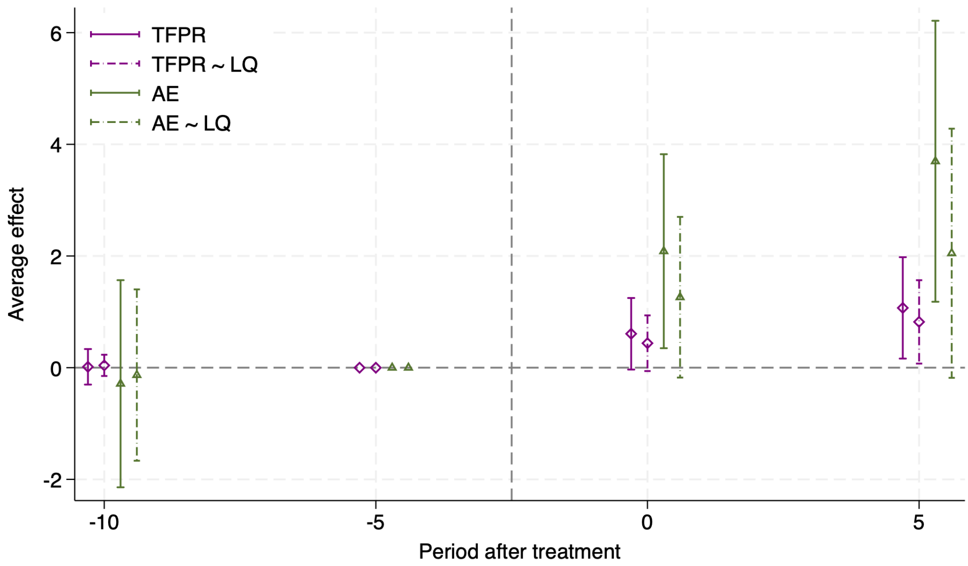


Figure A.10: Impact of Rail upgrades on productivity net of segregation

Table A.4: Industry classifications

1970	**1980 and 1985**
Major Group 1 - Food, excluding beverages	*Major Group* 1 - Food, excluding beverages
Major Group 2 - Beverage industries	*Major Group* 2 - Beverage industries
Major Group 3 - Tobacco	*Major Group* 3 - Tobacco
Major Group 4 - Textiles	*Major Group* 4 - Textiles
Major Group 5 - Clothing, footwear and made-up textile goods	*Major Group* 5 - Wearing apparel, except footwear
	Major Group 7 - Footwear
Major Group 6 - Wood and cork products, excluding furniture	*Major Group* 8 - Wood and cork products, excluding furniture
Major Group 7 - Furniture and fixtures	*Major Group* 9 - Furniture and fixtures, except primarily of metal
Major Group 8 - Paper and paper products	*Major Group* 10 - Paper and paper products
Major Group 9 - Printing, publishing and allied industries	*Major Group* 11 - Printing, publishing and allied industries
Major Group 10 - Leather and leather products	*Major Group* 6 - Leather and leather products excluding footwear and wearing apparel
Major Group 11 - Rubber products	*Major Group* 14 - Rubber products
Major Group 12 - Chemicals and chemical products	*Major Group* 12 - Industrial Chemicals
	Major Group 13 - Other chemical products
Major Group 13 - Non-metallic mineral products, excluding products of petroleum and coal	*Major Group* 18 - Other non-metallic mineral products
Major Group 14 - Basic metal industries	*Major Group* 19 - Iron and steel basic industries
	Major Group 20 - Non-Ferrous Metal Basic Industries
Major Group 15 - Metal products, excluding machinery and transport equipment	*Major Group* 21 - Fabricated Metal Products, except machinery and equipment
Major Group 16 - Machinery, excluding electrical machinery	*Major Group* 22 - Machinery except electrical
Major Group 17 - Electrical machinery, etc.	*Major Group* 23 - Electrical Machinery, apparatus, appliances and supplies
Major Group 18 - Transport equipment	*Major Group* 24 - Motor Vehicles, Parts and accessories
	Major Group 25 - Transport Equipment not elsewhere classified
Major Group 19 - Miscellaneous Industries	*Major Group* 15 - Plastic Products
	Major Group 16 - Pottery, China and earthenware
	Major Group 17- Glass and glass products
	Major Group 26- Professional and scientific and measuring and controlling equipment, and photographic and optical equipment
	Major Group 27- Other manufacturing industries

Notes: This table shows my mapping of industry classifications for the 1980 and 1985 manufacturing census data to 1970 the census industry classifications.