Urban Growth and Transportation

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Objective

- Assess the effects of transportation infrastructure, roads and public transit in particular, on the growth of cities.

Transportation is important #1

- Transportation and transportation infrastructure consume a large share of a developed economy's resources:
  - In 2002 the US spent 135.9 billion dollars on federal highways, about 1.3% of GDP.
  - American households devote about 20% of their expenditures to road transport (Glaeser and Kahn, 2004, United States Bureau of Transportation Statistics, 2004).

- Moreover, claims about the importance of of transportation to growth are common:

> The development and implementation of transportation infrastructure projects ... is essential to the well-being of the American people and a strong American economy.
>
> President G. Bush, September 18th, 2002

Given the magnitude of these expenditures, claims for their importance should not be made on the basis of the claims of advocacy groups. Are these resources being allocated wisely and well? Probably not.

Transportation is important #2

Roads and buses cause population increase and demographic change. An estimate of *the population growth elasticity of infrastructure* will help with planning the provision of complementary infrastructure like schools, sewers, power, and social services.

Transportation is important #3

- Transportation costs are among the most fundamental quantities in theoretical models of cities:
  - The Alonso-Muth-Mills monocentric framework (Brueckner, 1987, Fujita, 1989).
  - Multicentric extensions of AMM (Anas, Arnott, and Small, 1998).
- However, only a few papers provide empirical evidence for the role transportation costs in shaping cities, e.g., (Glaeser and Kahn, 2004, Baum-Snow, 2007).

Related literature

- Literature on urban growth:
  - A large literature investigates the role of agglomeration effects (Glaeser, Kallal, Scheinkman, and Schleifer, 1992, Henderson, Kuncoro, and Turner, 1995), human capital (Glaeser, Scheinkman, and Schleifer, 1995, Glaeser and Saiz, 2004), and climate (Glaeser, Kolko, and Saiz, 2001, Rappaport, 2007).
  - The role of transportation in growth is little studied.
- Literature on the determinants of country growth:
  - Very large cross-country literature following Barro (1991).
  - Cities are natural places in which to study economic growth (Lucas, 1988).

- Empirical literature on monocentric and multicentric model:
  - Much research examines land use and land prices within cities.
  - Few papers examine the relationship between transportation infrastructure/costs and population size (Brueckner, 1990, Baum-Snow and Kahn, 2000, Kopecky and Suen, 2006, Baum-Snow, 2007)
  - Fewer still examine the relationship between urban growth and transportation (Baum-Snow, 2007, Burchfield, Overman, Puga, and Turner, 2006)

- Literature on the effects of infrastructure investment:
  - Estimation of local production with public capital following Aschauer (1989) (see also Gramlich, 1994, Fernald, 1999, Haughwout, 2002).
  - Nascent literature modelling infrastructure supply (Haughwout and Inman, 2001, Cadot, Roller, and Stephan, 2006).

Equilibrium evolution of transportation infrastructure and population in four simple equations

How do cross-sectional changes in roads and buses in 1980 affect population changes between 1980 and 2000? Since roads are assigned to cities on the basis of their population growth, we need a model to sort this out:

1. City population and transportation costs in a static model.
2. Convergence to steady state in a dynamic model.
3. Transportation costs as a function of transportation infrastructure and population.
4. Equation of motion for transportation infrastructure.

Equation #1

The city is in equilibrium when worker locations and land rents adjust so that workers are indifferent between any location in the city and an alternate location:

$$w - 2\tau x - R(x) = W.$$

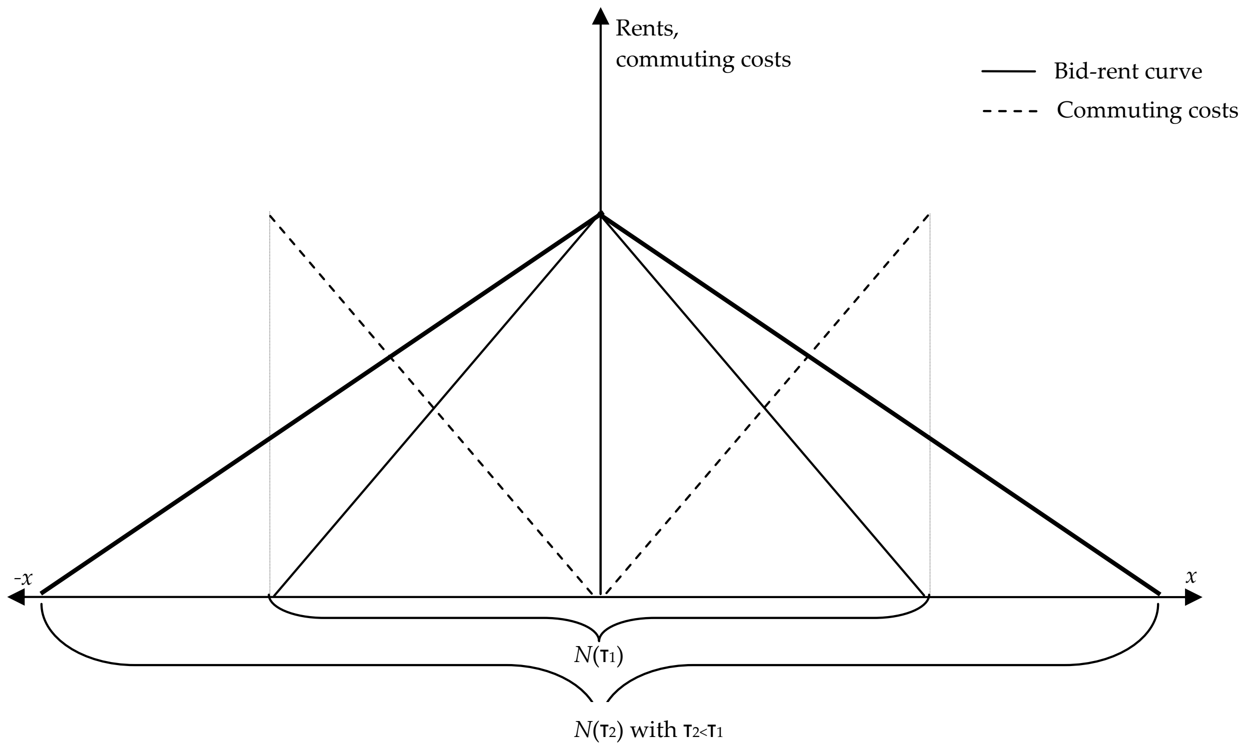
$\Longrightarrow$ Land rent at the city fringe is zero, i.e., $R(N^*/2) = 0$.

$\Longrightarrow$ (Generalizing a little) population in equilibrium:

$$N^* = \frac{A}{\tau^a},$$

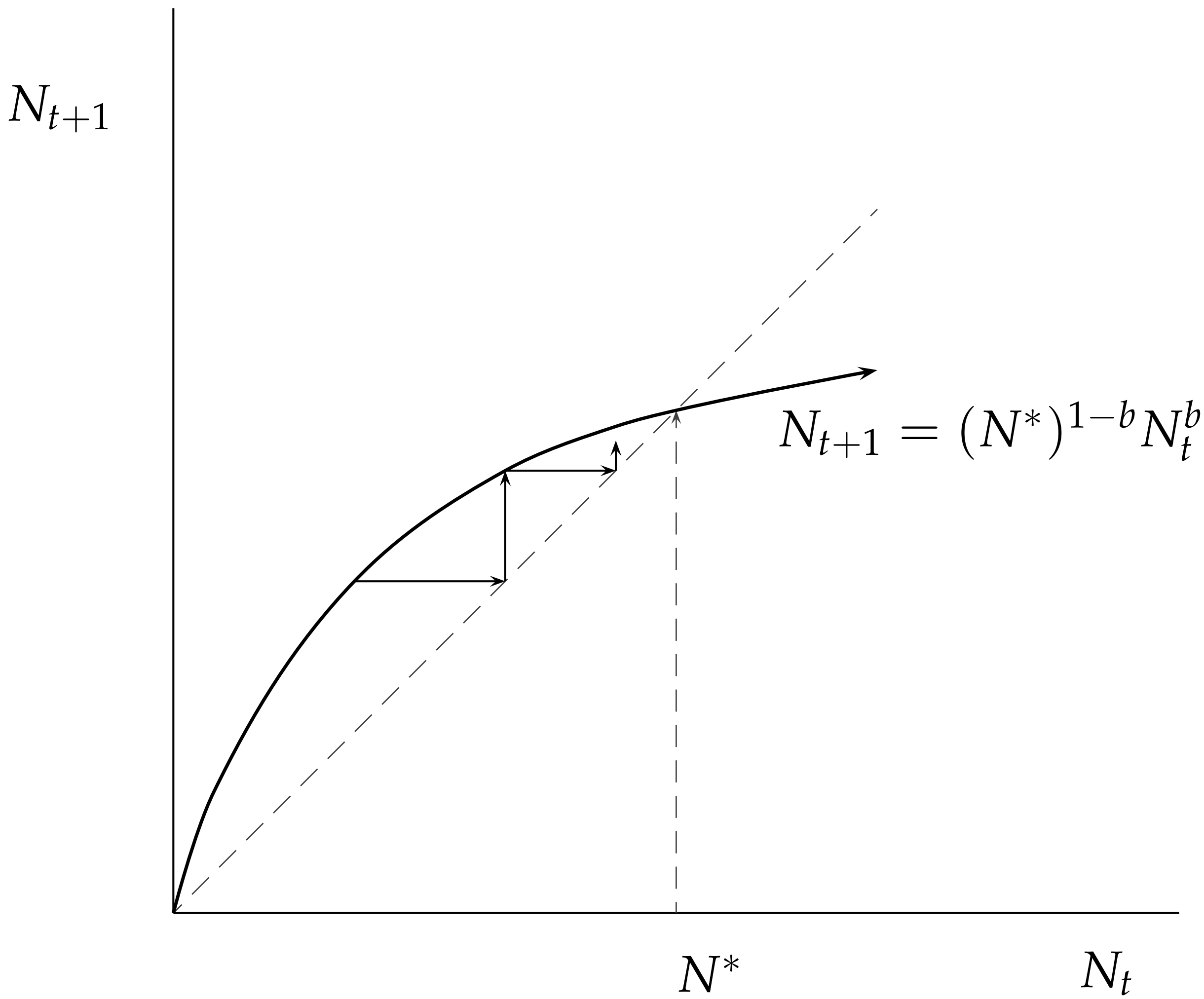
where A depends on local wages and the dollar value of local amenities.(In dynamic model A is stochastic).

That is, lower commuting costs must lead to larger equilibrium city populations.



- Changes in commuting costs are not reflected in wages but are reflected in population.
- Land rent and population are directly related, but population is easier to observe.

Equation #2



Equation #3

Unit transportation costs τ *at time* t;

- decrease with infrastructure at t,
- increase with Population at t,
- vary with local conditions like terrain and national conditions like gas prices.

Equation #4

Transportation infrastructure at t depends on:

- Transportation infrastructure at $t - 1$ net of depreciation.
- Population at $t - 1$.

Using this recursively, we have that *Transportation infrastructure at t* depends on, *past population levels*, *initial conditions*, and *local comparative advantage*.

Estimating equations

Putting it all together gives us our estimating equations:

$$\begin{aligned}
\ln R_{it} &= \sum_{j>0}^{t} F_j \ln N_{it-j} + H_1 Z_i + H_2 X_i + \mu_{it} , \\
\Delta \ln N_{it+1} &= B \cdot \left(X_i, (\ln N_{it-j})_{j=0}^{t} \right) + C_1 \widehat{\ln R_{it}} - C_2 \ln N_{it} - D_t + \epsilon_{it} .
\end{aligned}$$

We want to estimate C_1, the population growth rate elasticity of roads (and buses). The inference problem we must overcome is that $E(\mu\epsilon) \neq 0$.

We require an instrument Z satisfying:

- Exogeneity: $E(Z\epsilon) = 0$.
  (N.B. Not $E(Z\Delta \ln N) = 0$.)
- Relevance: $E(ZR_{80}|.) \neq 0$.

The trick is finding Z.

Required data

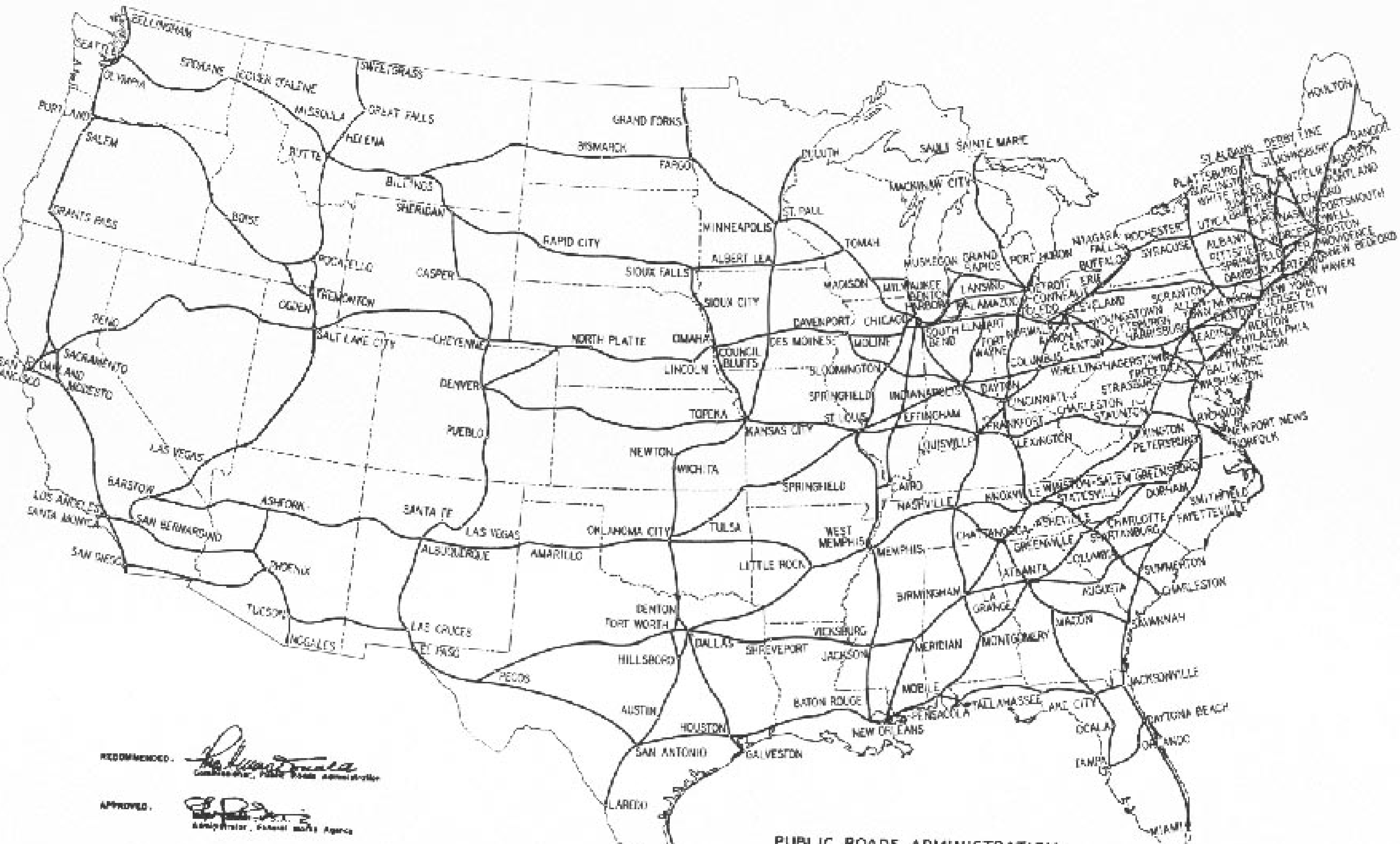
Our unit of observation will be a 1999 MSA/CMSA. We use:

- Population data from the US census since 1920.
- Roads 1980 – 1980 USGS digital line graphs.
- Count of light rail cars and buses — Section 15 data.
- Employment data from the County Business Patterns (CBP).
- Physical geography: availability of ground water, topography, climate, census divisions.
- Demographic variables from 1980 and 2000 censuses.

Z^1 – 1947 Highway Plan

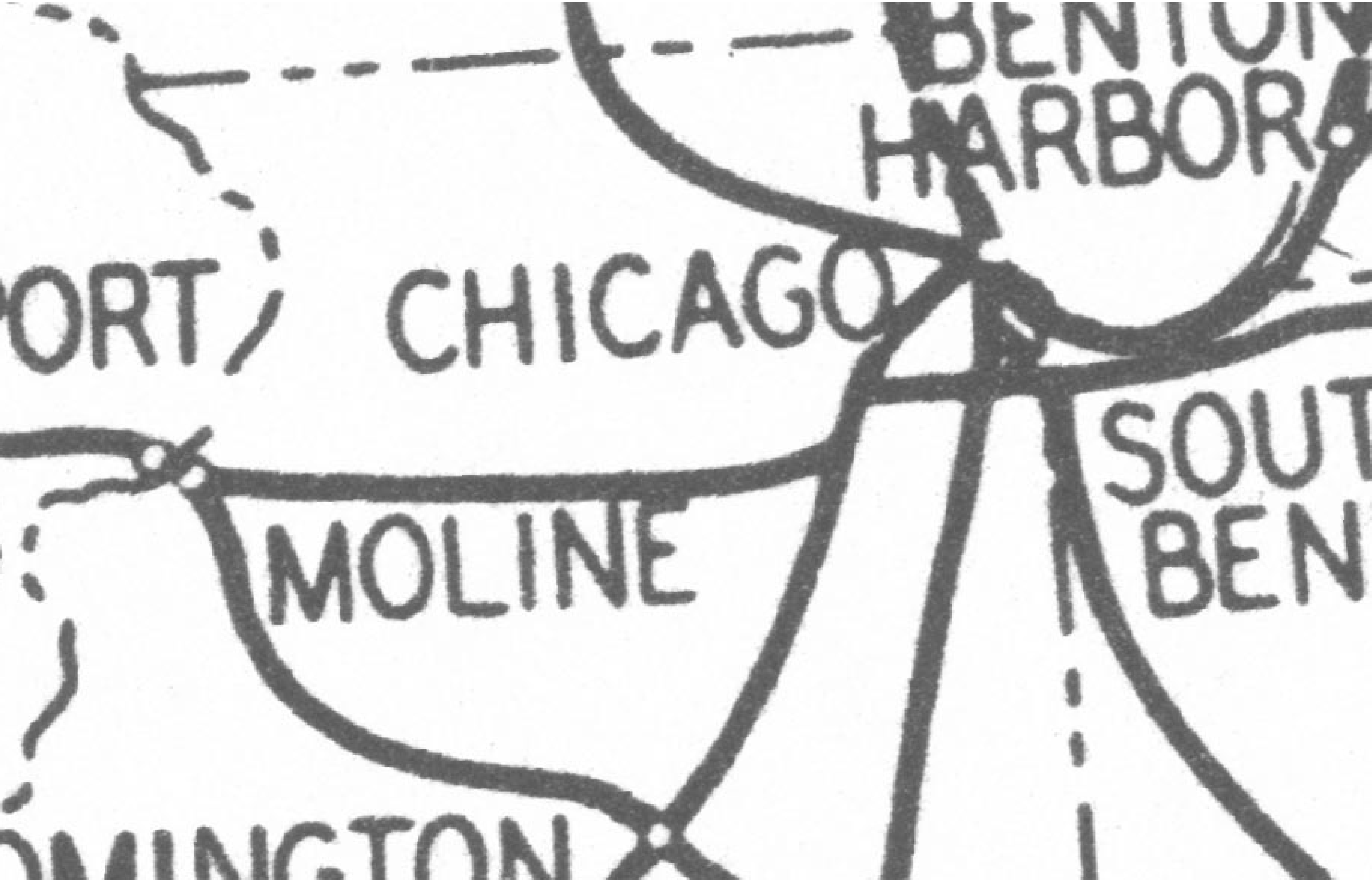
$Z^1 =$ *kilometers of planned interstate highway routes contained within each 1999* MSA (United States Federal Works Agency, Public Roads Administration, 1947).

- Relevance: The 1947 plan was by-and-large implemented after the 1956 Federal-Aid Highway Act.
- Exogeneity: The 1947 plan was first drawn to *'connect by routes as direct as practicable the principal metropolitan areas, cities and industrial centers, to serve the national defense and to connect suitable border points with routes of continental importance in the Dominion of Canada and the Republic of Mexico'* (United States Federal Works Agency, Public Roads Administration, 1947, cited in Michaels, 2006).



PUBLIC ROADS ADMINISTRATION
FEDERAL WORKS AGENCY

NATIONAL SYSTEM OF INTERSTATE HIGHWAYS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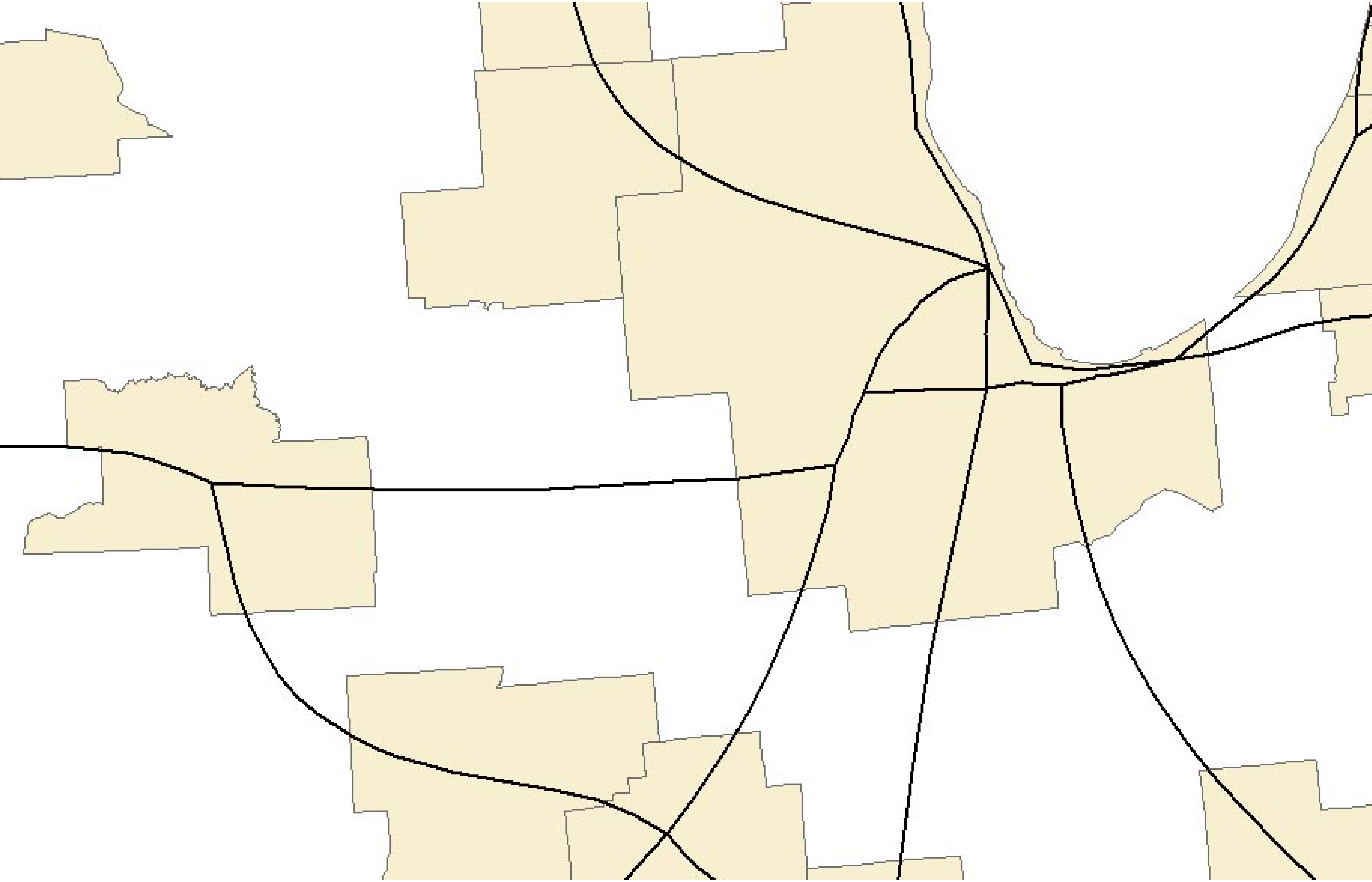
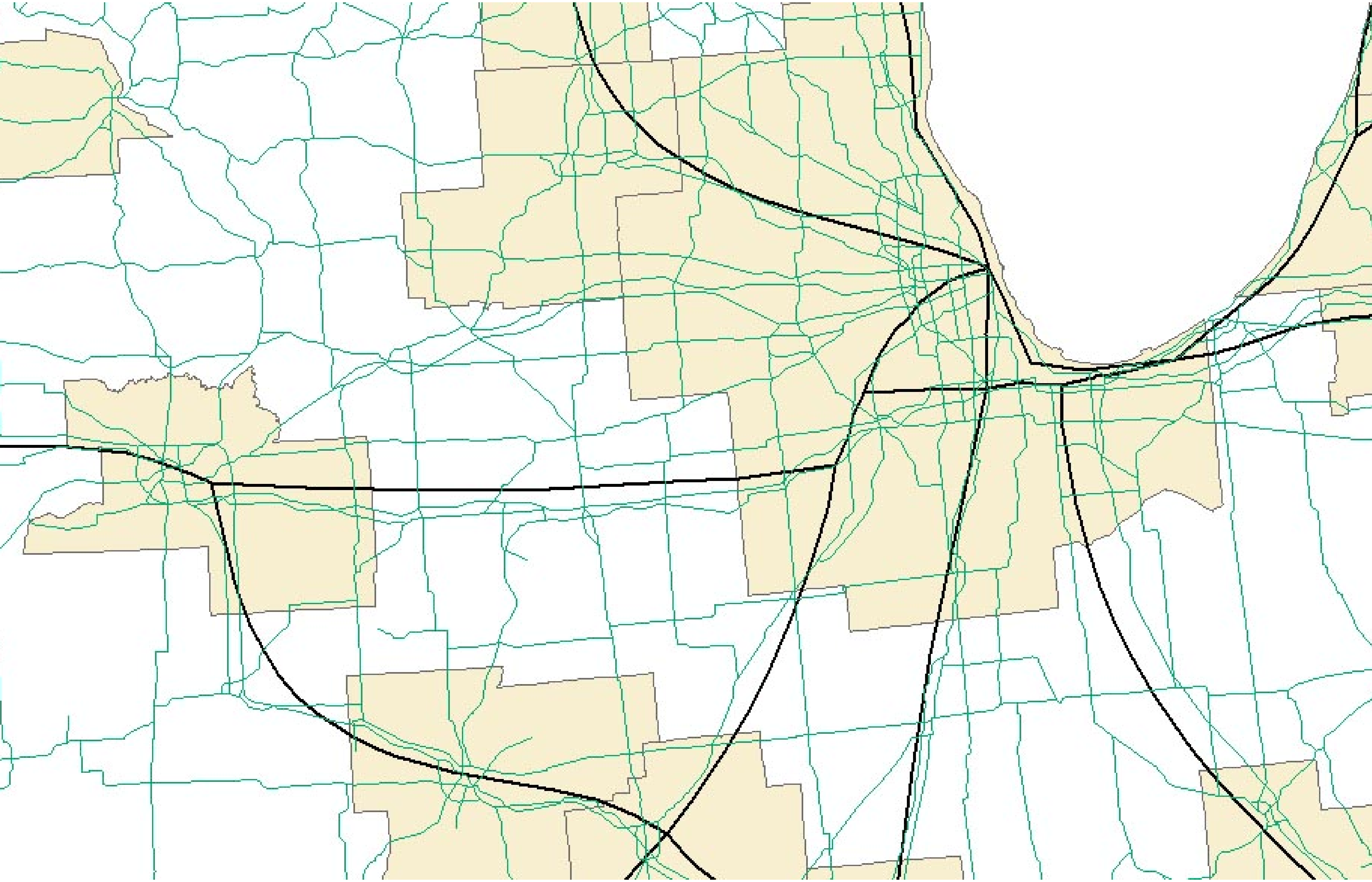
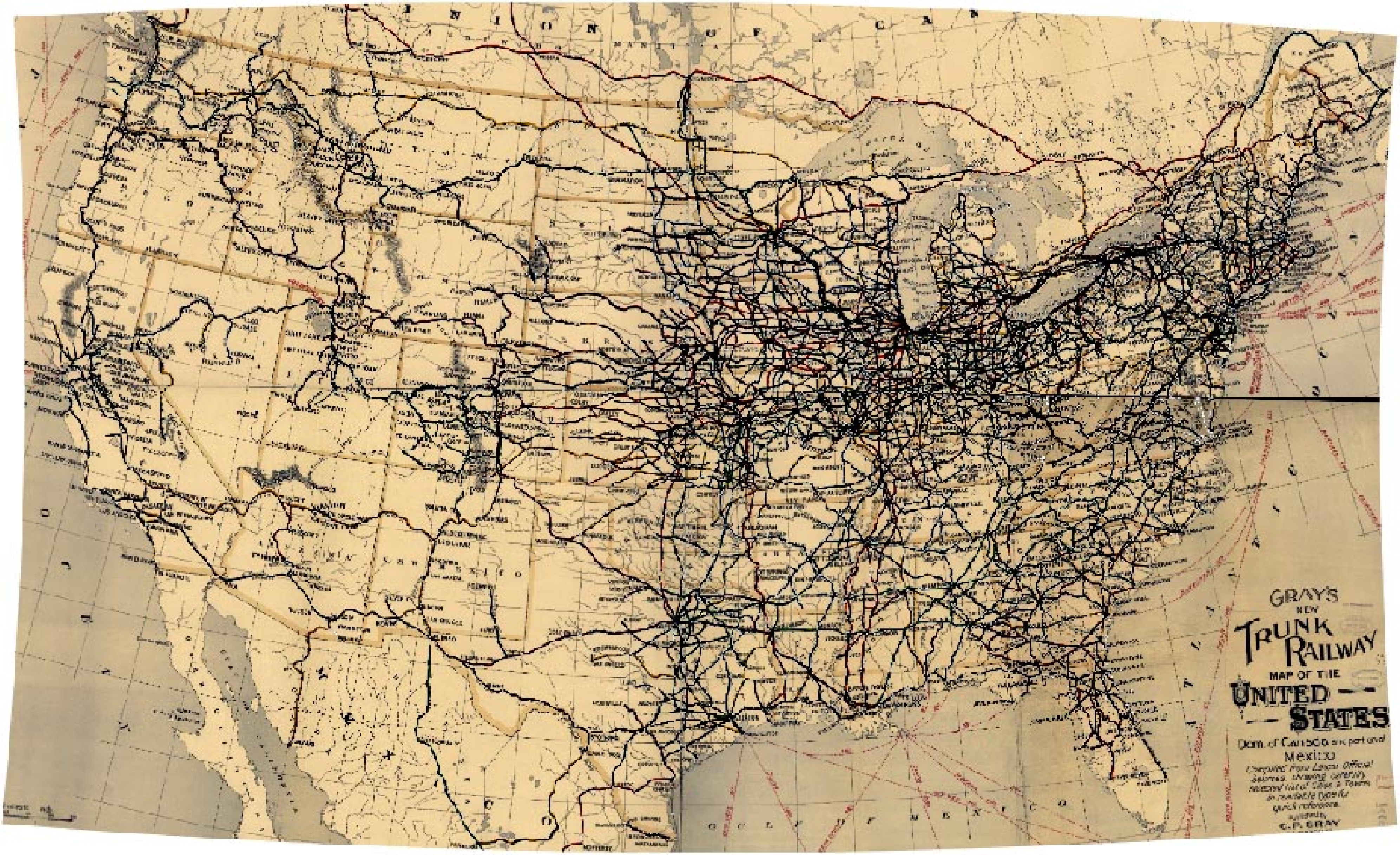




Z^2 – 1898 railroad routes

$Z^2 =$ *kilometers of railroad routes c.1898 contained within each 1999* MSA (Gray, c. 1898)

- Relevance: Railroad beds are good road beds.
- Exogeneity: (1) A very different economy; (2) Railroads were built for profit with no interest in population growth a hundred years later.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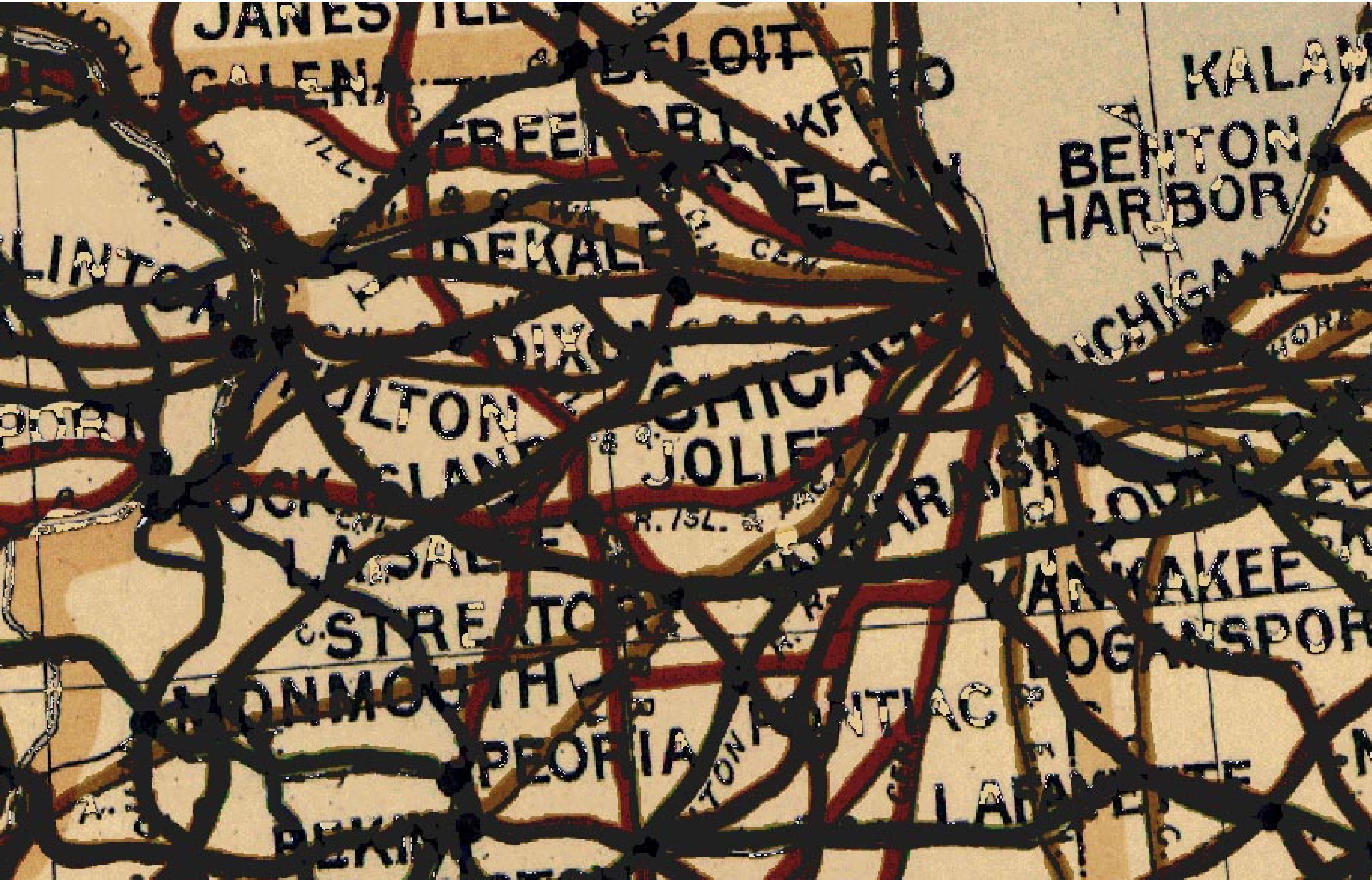
GULF OF MEXICO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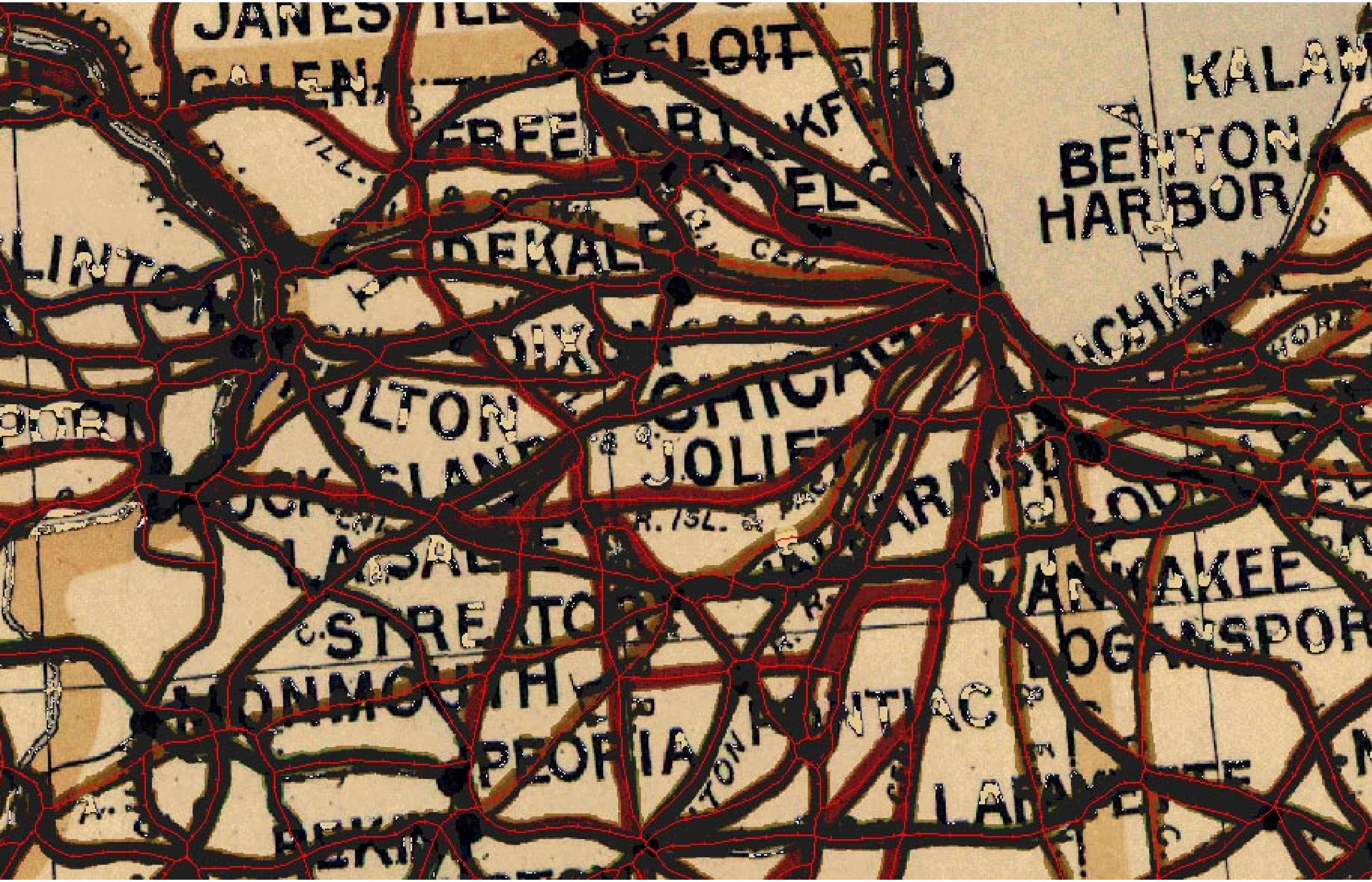
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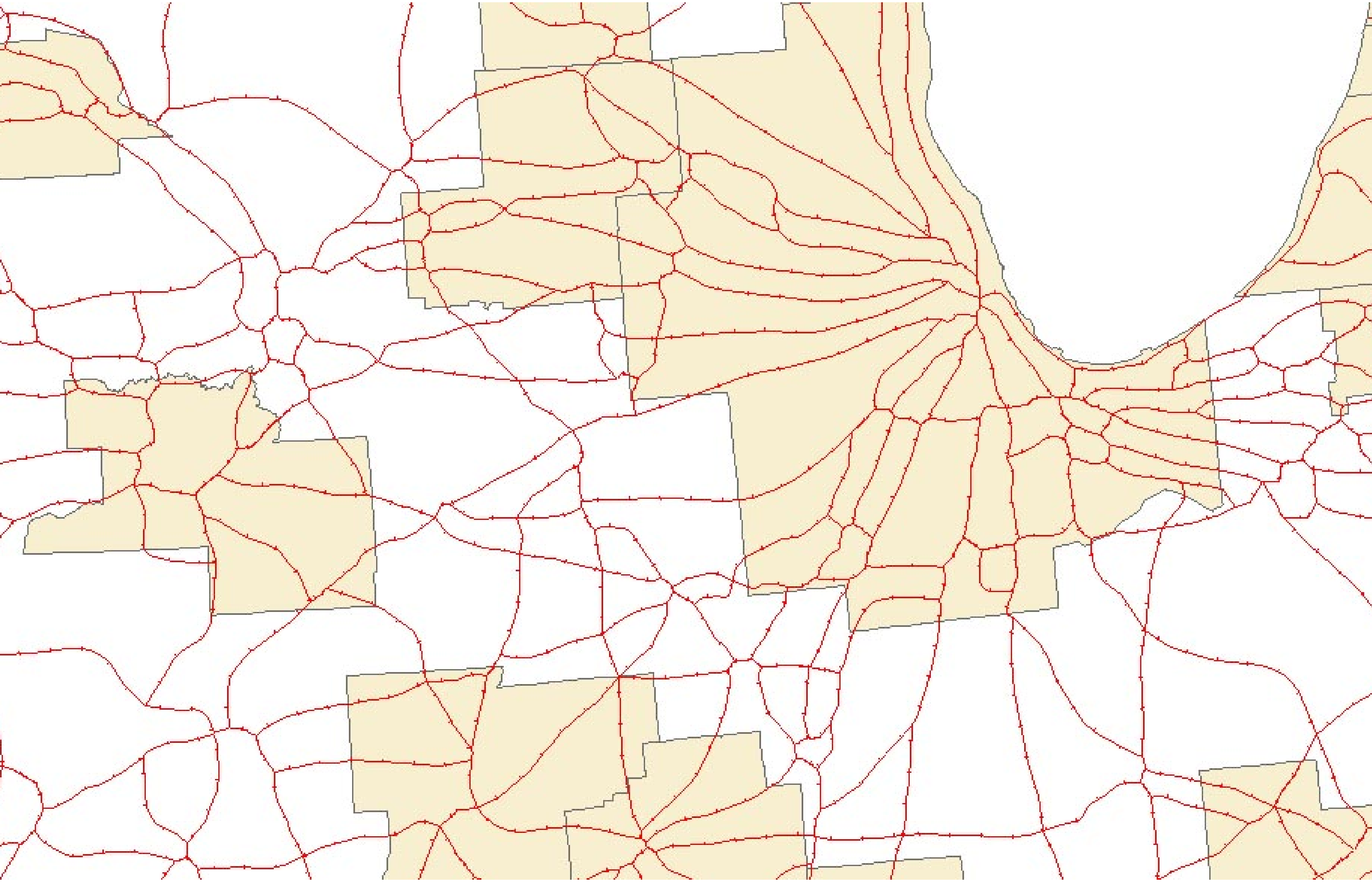
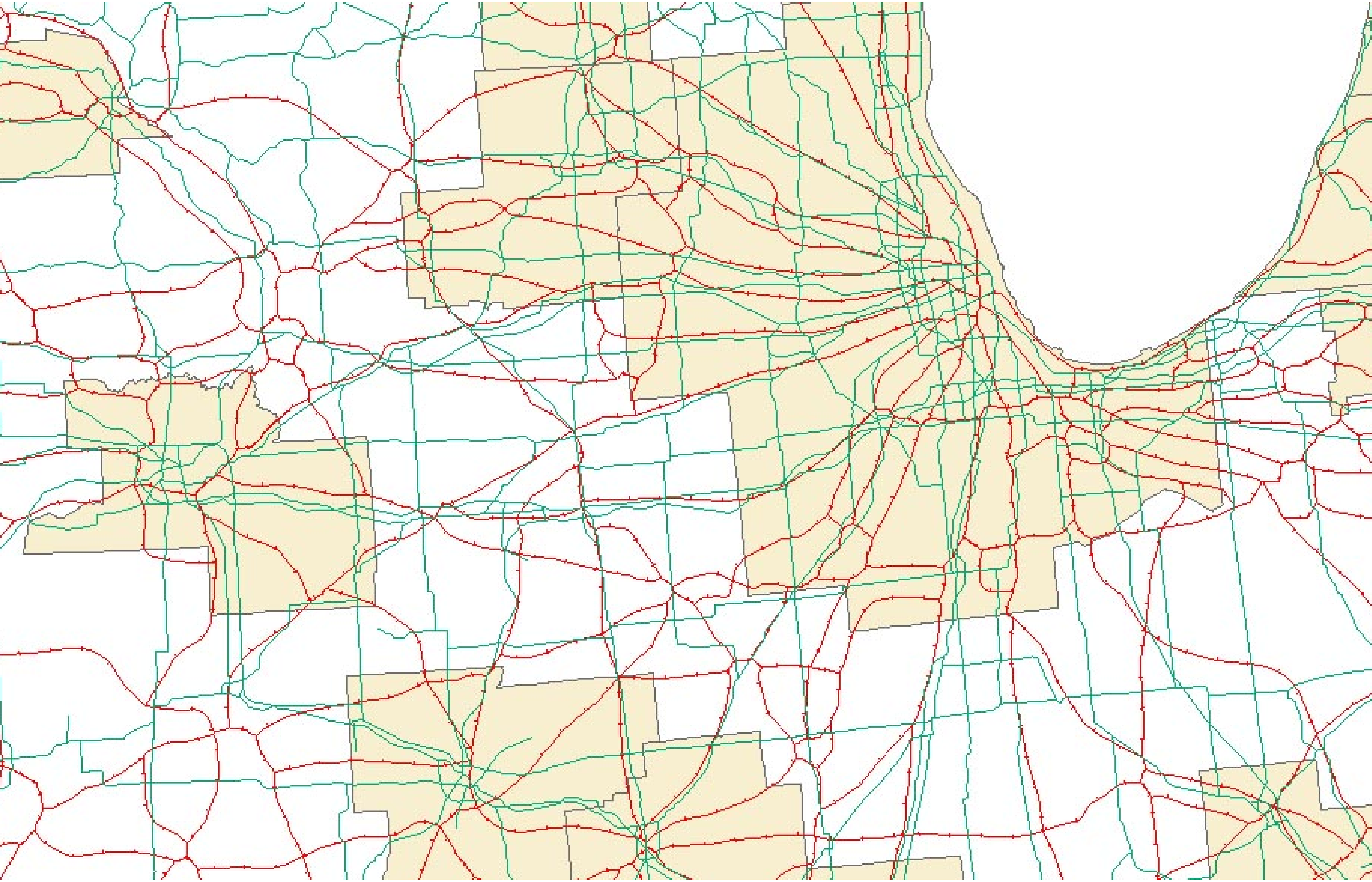
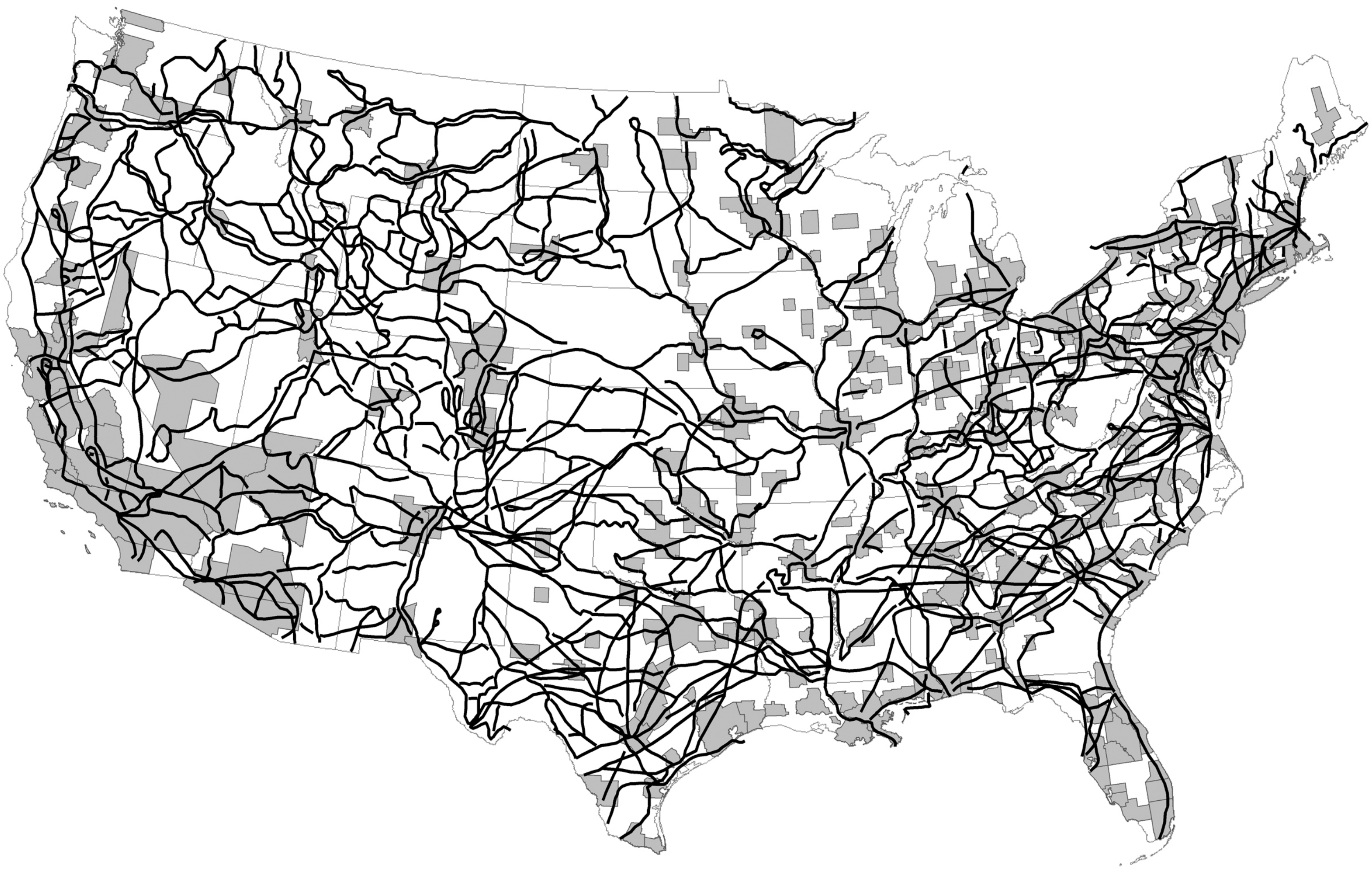
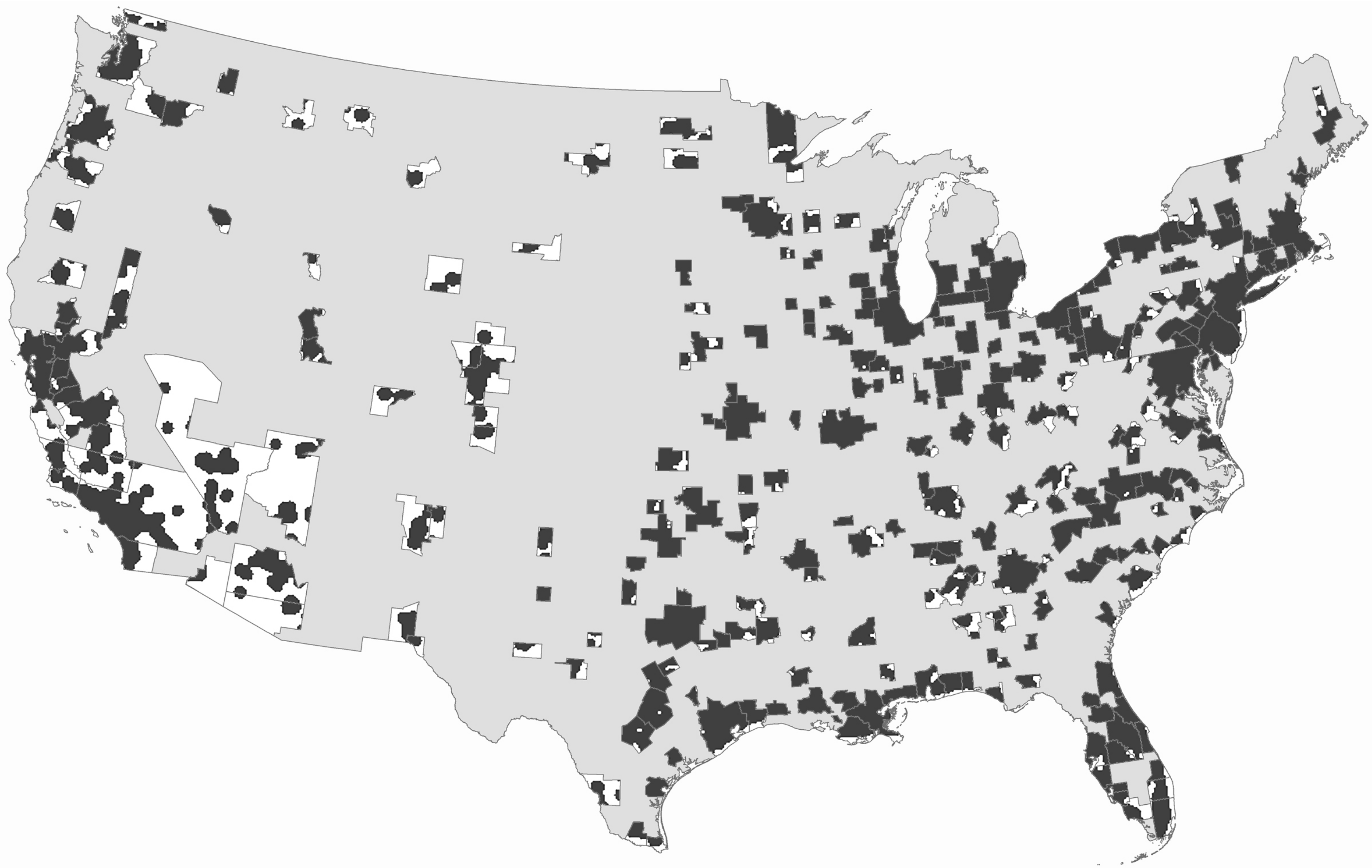




Z^3 – 1528-1850 exploration routes

Z^3 =*kilometers of exploration routes or for explorers between 1528 and 1850 contained within each 1999* MSA (United States Geological Survey, 1970, Maps of exploration and settlement between 1528 and 1850).





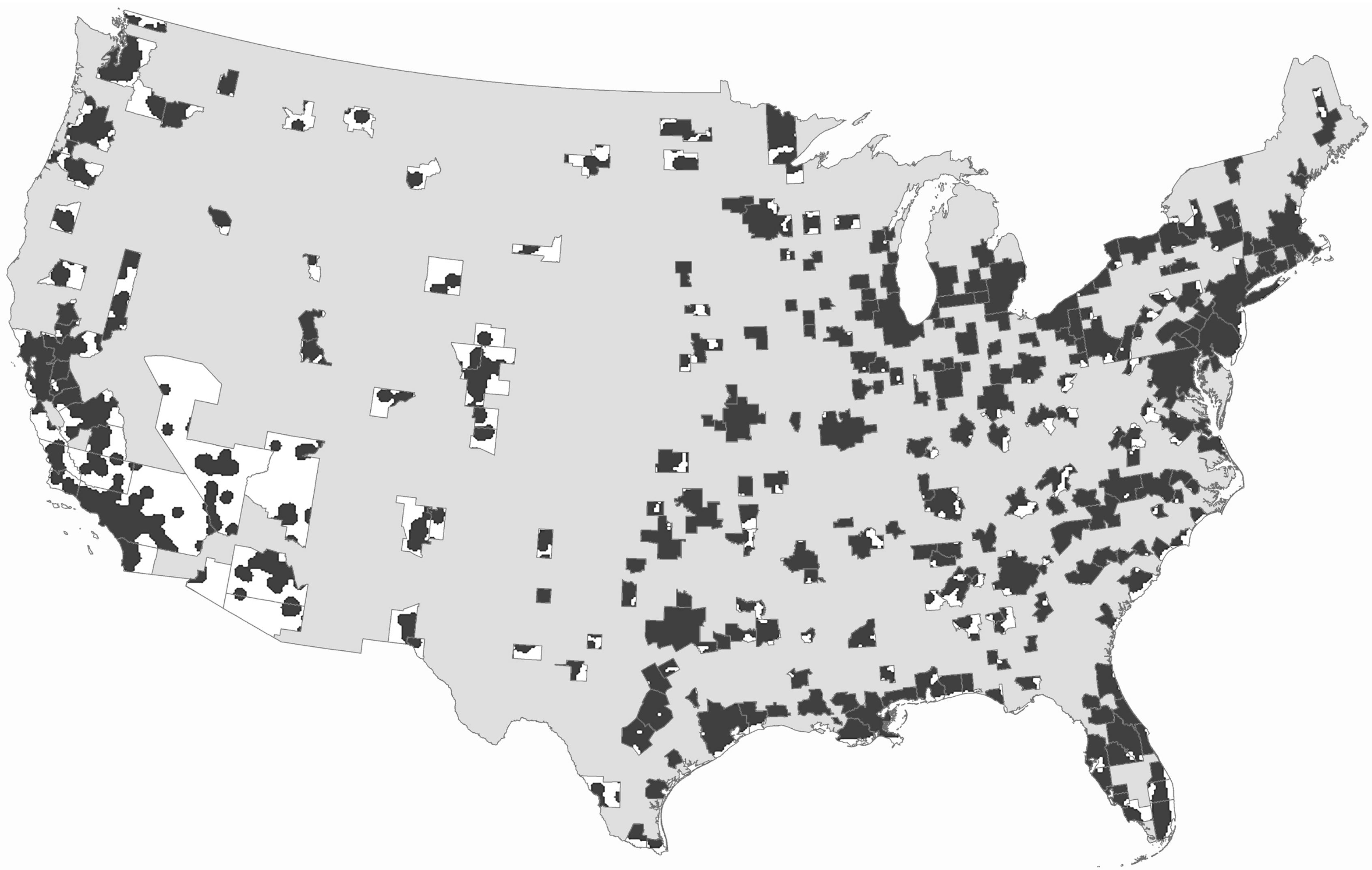


Table 1. Summary statistics for our main variables. Averages are across all 275 MSAs with 1999 boundaries.

	Mean	Std. dev.
1980 Population ('000)	648.3	1564.0
2000 Population ('000)	818.0	1908.6
1980-2000 Annual population growth (%)	1.1	1.2
1980 Employment ('000)	218.4	548.9
2000 Employment ('000)	349.6	790.3
1980-2000 Annual employment growth (%)	2.7	1.4
1980 Roads (km)	537.6	577.0
1980 Roads per 10,000 pop. (km)	15.9	8.1
1980 Peak service large buses	141.3	516.0
1980 Peak service large buses per 10,000 pop.	1.1	1.0
Aquifer (% area)	30.9	37.8
Elevation (m)	628.0	891.8
Ruggedness index	9.4	11.1
Heating degree days (days $\times$ F^o)	4580.8	2235.7
Cooling degree days (days $\times$ F^o)	1348.4	923.1
Planned 1947 highways (km)	88.6	109.5
1898 Railroads (km)	235.9	276.7

Table 2. Pairwise correlations: kilometers of modern roads and historical transportation networks

	ln(km 1980 roads)
ln(km 1947 highways)	0.63
ln(km 1898 railroad)	0.60

All variables computed for the developable area of each MSA drawn to 1999 boundaries.
275 observations.

Table 3. First stage

Variable	[1]	[2]	[3]	[4]	[5]	[6]	[7]
ln(Railroad routes)	0.064	0.107	0.098	0.108	0.122		0.114
	(0.028)[b]	(0.033)[a]	(0.031)[a]	(0.030)[a]	(0.030)[a]		(0.032)[a]
ln(Planned Interstate Hwy)	0.043	0.030	0.033	0.035		0.048	0.043
	(0.013)[a]	(0.013)[b]	(0.013)[b]	(0.013)[a]		(0.012)[a]	(0.014)[a]
$\ln(\text{Pop}_{80})$	Y	Y	Y	Y	Y	Y	Y
$\{\ln(\text{Pop}_t)\}_{t\in\{20,...70\}}$	N	Y	Y	Y	Y	Y	Y
Physical Geography	N	N	Y	Y	Y	Y	Y
Census Divisions	N	N	N	Y	N	N	N
R-squared	0.81	0.83	0.84	0.86	0.83	0.83	0.81
F-test (H_0 − All instruments zero)	11.01	11.23	12.28	16.11	16.33	16.09	17.76
Partial R-squared	0.08	0.10	0.10	0.12	0.07	0.05	0.14

Dependent variable: ln(1980 road km.).
All regressions include a constant. Robust standard errors in parentheses.
275 observations for each regression.
1980 roads and instruments are calculated for the developable area of each MSA, except for columns 7 where calculations are based on the whole area of the MSA.
a, *b*, *c*: significant at 1%, 5%, 10%.

Table 4. Population growth rate 1980-2000 as a function of 1980 roads

Variable	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
	OLS	OLS	OLS	TSLS	TSLS	TSLS	TSLS	TSLS	TSLS
ln(1980 road km.)	0.128	0.042	0.049	0.210	0.180	0.177	0.231	0.180	-0.286
	$(0.042)^a$	$(0.021)^b$	$(0.024)^b$	$(0.069)^a$	$(0.060)^a$	$(0.062)^a$	$(0.069)^a$	$(0.061)^a$	(0.195)
$\ln(\text{Pop}_{80})$	-0.078	0.892	0.850	0.652	0.639	0.640	0.770	0.663	0.178
	$(0.030)^b$	$(0.104)^a$	$(0.119)^a$	$(0.170)^a$	$(0.164)^a$	$(0.165)^a$	$(0.152)^a$	$(0.175)^a$	(0.118)
$\{\ln(\text{Pop}_t)\}_{t\in\{20,...70\}}$	N	Y	Y	Y	Y	Y	Y	Y	N
Physical Geography	N	Y	Y	Y	Y	Ext.	N	Y	N
Census Divisions	N	N	Y	N	Y	Y	N	N	N
Instruments used:									
ln(Planned Interstate Hwy.)	-	-	-	Y	Y	Y	Y	Y	Y
ln(Railroad routes)	-	-	-	Y	Y	Y	Y	Y	Y
First stage F-test	-	-	-	12.28	16.11	14.70	11.23	17.76	11.01
(H_0 − All instruments zero)									
Over-id test p-value	-	-	-	0.61	0.57	0.51	0.66	0.43	0.00
R-squared	0.04	0.74	0.77	-	-	-	-	-	-

Dependent variable: $\Delta_{00,80} \ln Pop$.
All regressions include a constant. Robust standard errors in parentheses.
275 observations for each regression.
1980 roads and instruments are calculated for the developable area of each MSA, except for column 8 where calculations are based on the whole area of the MSA
a, b, c: significant at 1%, 5%, 10%.

Table 5. Evidence for road construction during bad times

Variable	[1]	[2]	[3]	[4]	[5]	[6]	[7]
$\Delta_{00,80}$Pop	-0.005	-0.005	-0.008	-0.009			
	$(0.003)^{c}$	$(0.002)^{b}$	$(0.003)^{b}$	$(0.003)^{a}$			
$\Delta_{80,70}$Pop					-0.318	-0.255	-0.194
					$(0.07)^{a}$	$(0.092)^{a}$	$(0.113)^{c}$
Share of Employment in non-road construction				0.293			
				$(0.147)^{b}$			
Physical Geography	Y	Y	Y	Y	N	N	Y
Census Divisions	N	Y	Y	Y	N	Y	Y
$\ln(\text{Pop}_{80})$	N	Y	Y	Y	N	N	N
$\{\ln(\text{Pop}_t)\}_{t\in\{20,\ldots 70\}}$	N	N	Y	Y	N	N	N
R-squared	0.19	0.30	0.34	0.39	0.06	0.20	0.26

Dependent variable in columns 1-4 is employment share in road construction.
Dependent variable in columns 5-7 is: log 1990 road km − log 1980 road km.
All regressions OLS with a constant. Robust standard errors in parentheses.
275 observations for each regression.
Measures of roads are calculated for the developable area of each MSA.
a, *b*, *c*: significant at 1%, 5%, 10%.

Table 6. Robustness to econometric strategy

Variable	[1] LIML	[2] TSLS	[3] TSLS
ln(1980 road km.)	0.210	0.232	0.174
	(0.079)[a]	(0.076)[a]	(0.103)[c]
Instruments used:			
ln(Railroad routes)	Y	Y	N
ln(Planned Interstate Hwy.)	Y	N	Y
Lower CLR	0.07	-	-
Upper CLR	0.42	-	-
First stage F-test (H_0 − All instruments zero)	13.83	16.33	16.09

Dependent variable: $\Delta_{00,80} \ln Pop$
All regressions include a constant and control for decennial population from 1920-80 and physical geography. Robust standard errors in parentheses (except LIML).
275 observations for each regression.
a, b, c: significant at 1%, 5%, 10%.
1980 roads and instruments are calculated for the developable area of each MSA.

Table 7. Robustness to change of specification

Variable	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
ln(1980 road km.)	0.145	0.066	0.192	0.121	0.071	0.311	0.240	0.204
	(0.050)[a]	(0.031)[b]	(0.108)[c]	(0.090)	(0.051)	(0.087)[a]	(0.116)[b]	(0.077)[a]
First stage F-test (H_0 − All instruments zero)	12.28	12.28	12.28	12.28	12.28	4.32	6.77	11.22
Over-id test p-value	0.62	0.71	0.34	0.37	0.61	0.05	0.84	0.57
Observations	275	275	275	275	275	81	194	253

Dependent variable by column: (1): $\Delta_{90,80} \ln Pop$, (2): $\Delta_{00,90} \ln Pop$, (3): $\Delta_{00,80} \ln Emp$, (4): $\Delta_{90,80} \ln Emp$, (5): $\Delta_{00,90} \ln Emp$, (6): $\Delta_{00,80} \ln Pop$ for cities with $Pop > 0.5$,
(7): $\Delta_{00,80} \ln Pop$ for cities with $Pop \leq 0.5$m,
(8): $\Delta_{00,80} \ln Pop$ for cities with $Pop > 2$m.
All regressions include a constant and control for decennial population 1920-80 and physical geography. Robust standard errors in parentheses.
In all regressions, roads are instrumented by 1898 railroads and 1947 highways.
1980 roads and instruments are calculated for the developable area of each MSA.
a, b, c: significant at 1%, 5%, 10%.

Table 8. Long run effects of rail on population growth

Variable	[1]	[2]	[3]
ln(1898 railroad routes)	0.541	0.348	0.328
	(0.126)[a]	(0.085)[a]	(0.098)[a]
$\ln(\text{Pop}_{1920})$	-0.373	-0.192	-0.147
	(0.092)[a]	(0.064)[a]	(0.063)[b]
Physical Geography	N	Y	Y
Census Divisions	N	N	Y
R-squared	0.13	0.65	0.73
Observations	117	117	117

Dependent variable: $\Delta_{00,20} \ln Pop$.
All regressions include a constant. Robust standard errors in parentheses.
Measures of 1898 railroads are calculated for the developable area of each MSA.
a, *b*, *c*: significant at 1%, 5%, 10%.

Table 9. Population growth rate 1980-2000 and network effects

Variable	[1]	[2]
ln(1980 road km.)	0.217	0.216
	(0.072)[a]	(0.072)[a]
ln(Neighbor road$_{80}$)	0.009	-
	(0.018)	-
ln(Neighbor gravity$_{80}$)	-	0.003
	-	(0.006)
First stage F-test	12.44	12.24
(H_0 − All instruments zero)		
Over-id test p-value	0.66	0.67

Dependent variable: $\Delta_{00,80} \ln Pop$.
All regressions include a constant and control for decennial population 1920-80 and physical geography. Robust standard errors in parentheses.
275 observations for each regression.
In all regressions, MSA roads are instrumented by 1898 railroads and 1947 highways.
1980 roads and instruments are calculated for the developable area of each MSA, except for column 8 where calculations are based on the whole area of the MSA
a, b, c: significant at 1%, 5%, 10%.

Transportation and specialization

We could find no evidence that roads affect the composition of economic activity in a city.

Why you should believe us:

- Relevance and exogeneity are ex ante defensible and consistent with theory.
- Relevance and strength of instruments is confirmed by first stage test statistics.
- There is out of sample verification of the bias that IV corrects.
- Over-id test fails without historical population controls.
- Both instruments result in the same coefficient estimates.
- Results are robust to LIML and CLR vs. TSLS, Employment vs. population, choice of controls.
- Magnitude of estimated effect of roads is consistent long run effects of rail.
- No evidence that roads operate by affecting trade.

Table 10. Population growth rate 1980-2000 as a function of 1984 buses and 1980 roads

Variable	[1] OLS	[2] OLS	[3] OLS	[4] TSLS	[5] TSLS	[6] TSLS	[7] TSLS	[8] TSLS
ln(1984 buses)	-0.031	0.007	0.004	0.078	0.069	0.069		0.068
	$(0.011)^a$	(0.007)	(0.008)	$(0.040)^b$	(0.044)	$(0.035)^b$		$(0.029)^b$
ln(1984 transit)							0.078	
							$(0.040)^b$	
ln(1980 road km.)	0.115	0.043	0.050	0.239	0.201	0.189	0.244	
	$(0.042)^a$	$(0.021)^b$	$(0.024)^b$	$(0.089)^a$	$(0.080)^b$	$(0.071)^a$	$(0.090)^a$	
$\ln(\text{Pop}_{80})$	Y	Y	Y	Y	Y	Y	Y	Y
$\{\ln(\text{Pop}_t)\}_{t\in\{20,\dots 70\}}$	N	Y	Y	Y	Y	Y	Y	Y
Physical Geography	Y	Y	Y	Y	Ext.	Y	Y	Y
Census Divisions	N	N	Y	N	Y	N	N	N
Instruments used:								
ln(Planned Interstate Hwy.)	-	-	-	Y	Y	Y	Y	N
ln(Railroad routes)	-	-	-	Y	Y	Y	Y	N
1972 share of democratic vote	-	-	-	Y	Y	Y	Y	Y
First stage statistics	-	-	-	5.06	3.94	5.62	5.02	17.27
(H_0 − All instruments zero)								
Over-id test p-value	-	-	-	0.81	0.50	0.71	0.83	-
R-squared	0.06	0.75	0.77	-	-	-	-	-

Dependent variable: $\Delta_{00,80} \ln Pop$.
All regressions include a constant. Robust standard errors in parentheses.
275 observations for each regression.
1980 roads and instruments are calculated for the developable area of each MSA, except for column 6 where calculations are based on the whole area of the MSA
a, b, c: significant at 1%, 5%, 10%.

Table 11. Transportation and the social composition of cities

Variable	[1]	[2]	[3]	[4]	[5]	[6]	[7]
	OLS	TSLS	OLS	TSLS	OLS	TSLS	TSLS
ln(1984 buses)	0.001	0.009			0.001	0.007	0.008
	(0.002)	(0.004)^b			(0.002)	(0.004)^c	(0.004)^b
ln(1980 road km.)			-0.013	-0.037	-0.013	-0.044	-0.039
			(0.005)^b	(0.016)^b	(0.005)^b	(0.016)^a	(0.016)^a
ln(Pop_{80})	-0.001	-0.013	0.009	0.024	0.008	0.017	0.014
	(0.003)	(0.007)^c	(0.004)^b	(0.010)^b	(0.005)	(0.012)	(0.013)
Share poor 1980	-0.586	-0.560	-0.586	-0.580	-0.585	-0.555	
	(0.035)^a	(0.042)^a	(0.036)^a	(0.037)^a	(0.035)^a	(0.040)^a	
Share dropouts 1980							-0.444
							(-0.054)^a
Instruments used:							
ln(Planned Interstate Hwy.)	-	-	-	Y	-	Y	Y
ln(Railroad routes)	-	-	-	Y	-	Y	Y
1972 share of democratic vote	-	Y	-	-	-	Y	Y
First stage statistics	-	58.36	-	13.41	-	10.03	9.85
(H_0 − All instruments zero)							
Over-id test p-value	-	-	-	0.30	-	0.18	0.11
R-squared	0.72	-	0.72	-	0.72	-	

Dependent variable: $\Delta_{00,80}$Share poor in col 1–6 and $\Delta_{00,80}$Share dropouts in col 7.
All regressions include a constant. Robust standard errors in parentheses.
275 observations for each regression.
1980 roads and instruments are calculated for the developable area of each MSA.
a, b, c: significant at 1%, 5%, 10%.

Why you should believe us:

- Relevance and exogeneity are consistent with other evidence from the literature.
- Relevance and strength of instruments is confirmed by first stage test statistics.
- There is out of sample verification of the bias that IV corrects.
- Corollary implication that buses attract poor is confirmed.
- Results pass over-id tests.
- Results are robust to LIML and CLR vs. TSLS and choice of controls.

Conclusion

- Roads have large effects on urban growth.
- Transportation infrastructure has very persistent effects.
- The supply of roads appear to be driven by short-term considerations.
- Buses also have a measurable effect on urban growth.

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