Amplified Gains from Transportation Infrastructure Investments

Richard Hornbeck
V. Duane Rath Professor of Economics
University of Chicago, Booth

2025 Leon N. Moses Distinguished Lecture in Transportation

What Gains from Transportation Infrastructure?

What is the value of something?

Economics generally values things based on how much people are willing to pay for them

- Fogel's Nobel Prize, social savings method
- Land values, hedonic method

What Gains from Transportation Infrastructure?

What is the value of something?

Economics generally values things based on how much people are willing to pay for them

- Fogel's Nobel Prize, social savings method
- Land values, hedonic method

But, the gains can be much larger

- When the economy has "distortions"
- Aggregate productivity growth without technological innovation

Canonical Infrastructure: The Railroads

Did railroads have substantial impact on American economic growth?

- Fogel argued no: social savings upper bound (2.7% of GDP)

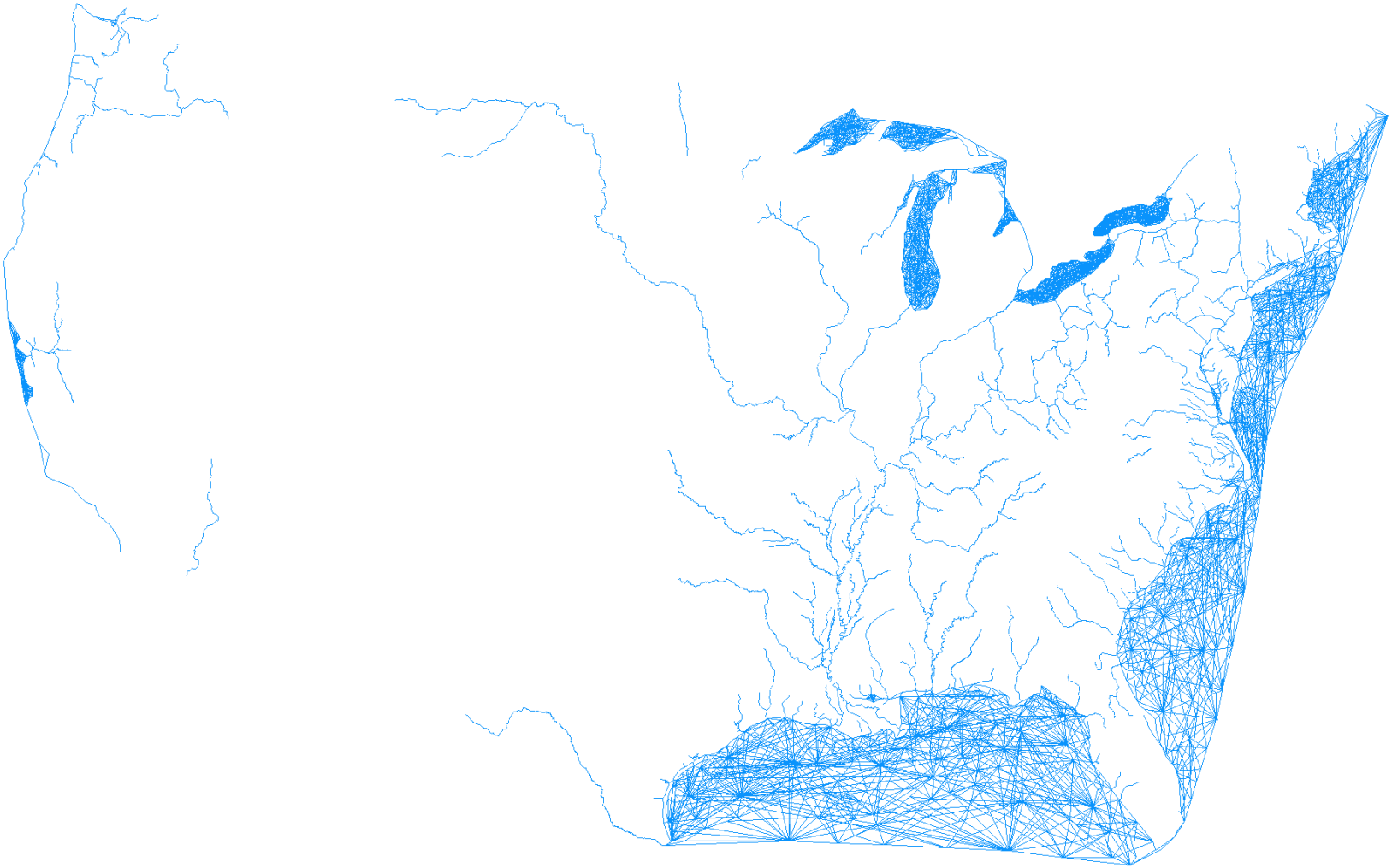
Social Savings:

- Cost of accommodating the absence of a technology
- Upper bound because it does not allow activity to decline

Implies one technology cannot substantially drive economic growth

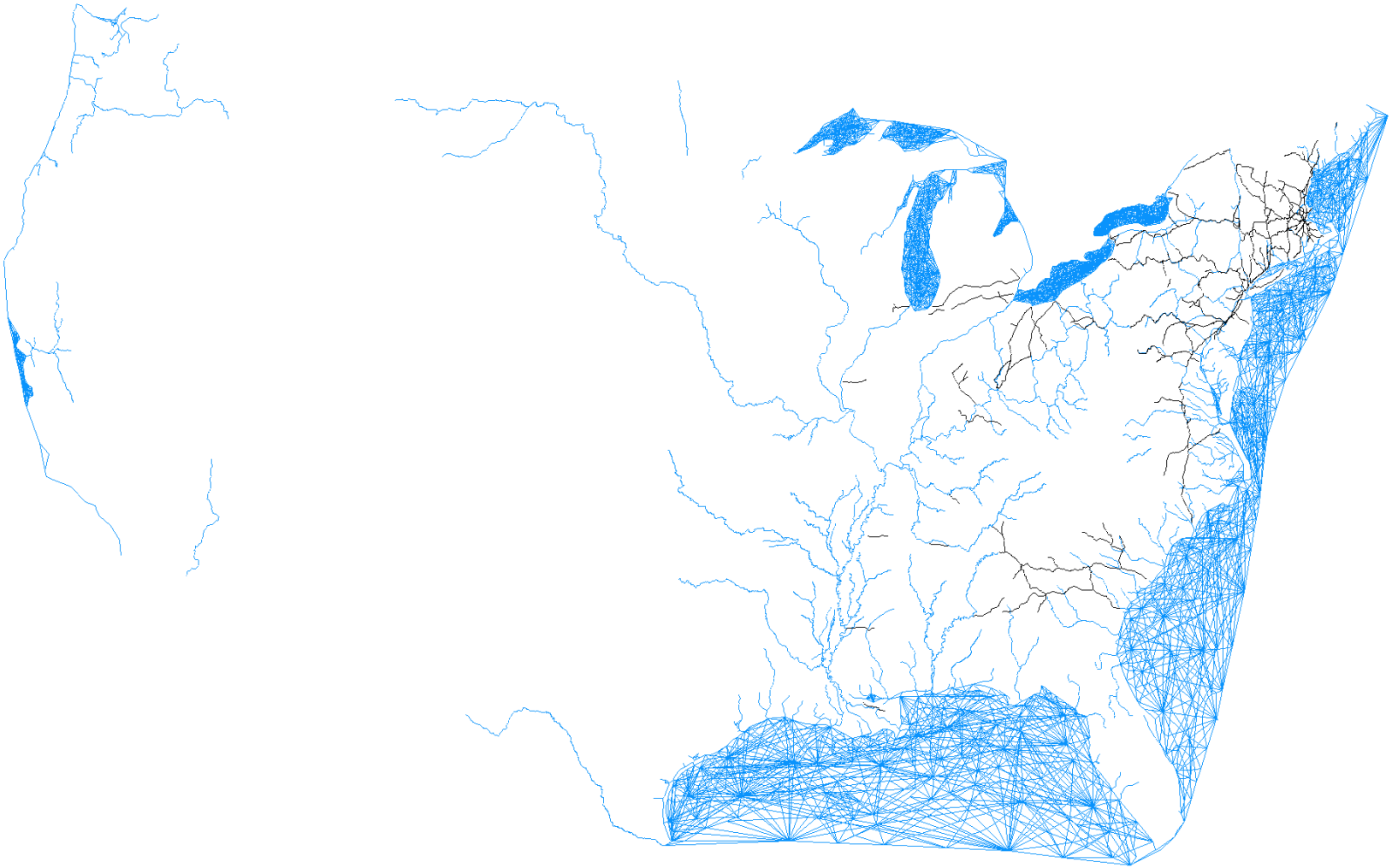
Change in Transportation Network

Waterways and No Railroads



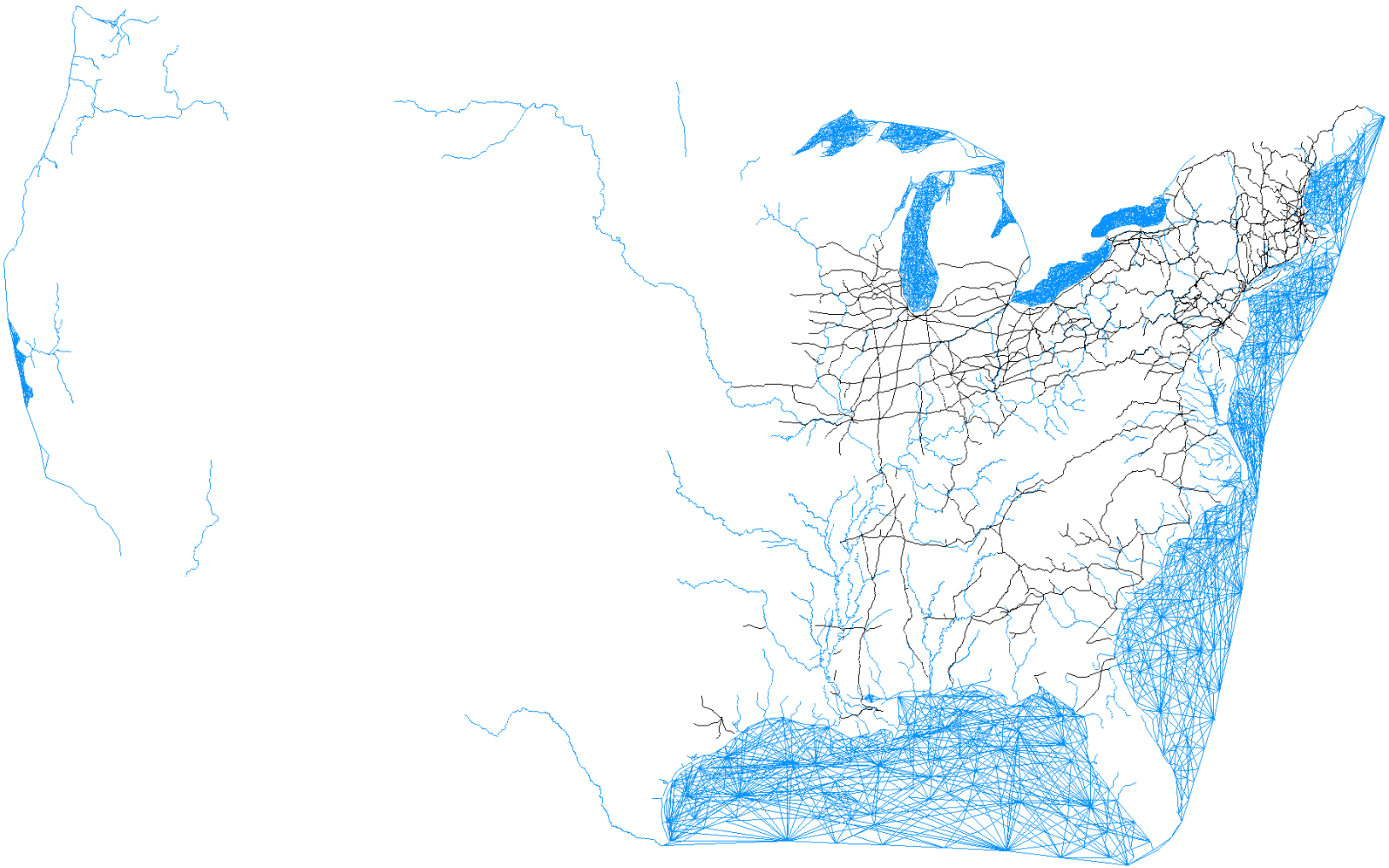
Change in Transportation Network

Waterways and 1850 Railroads



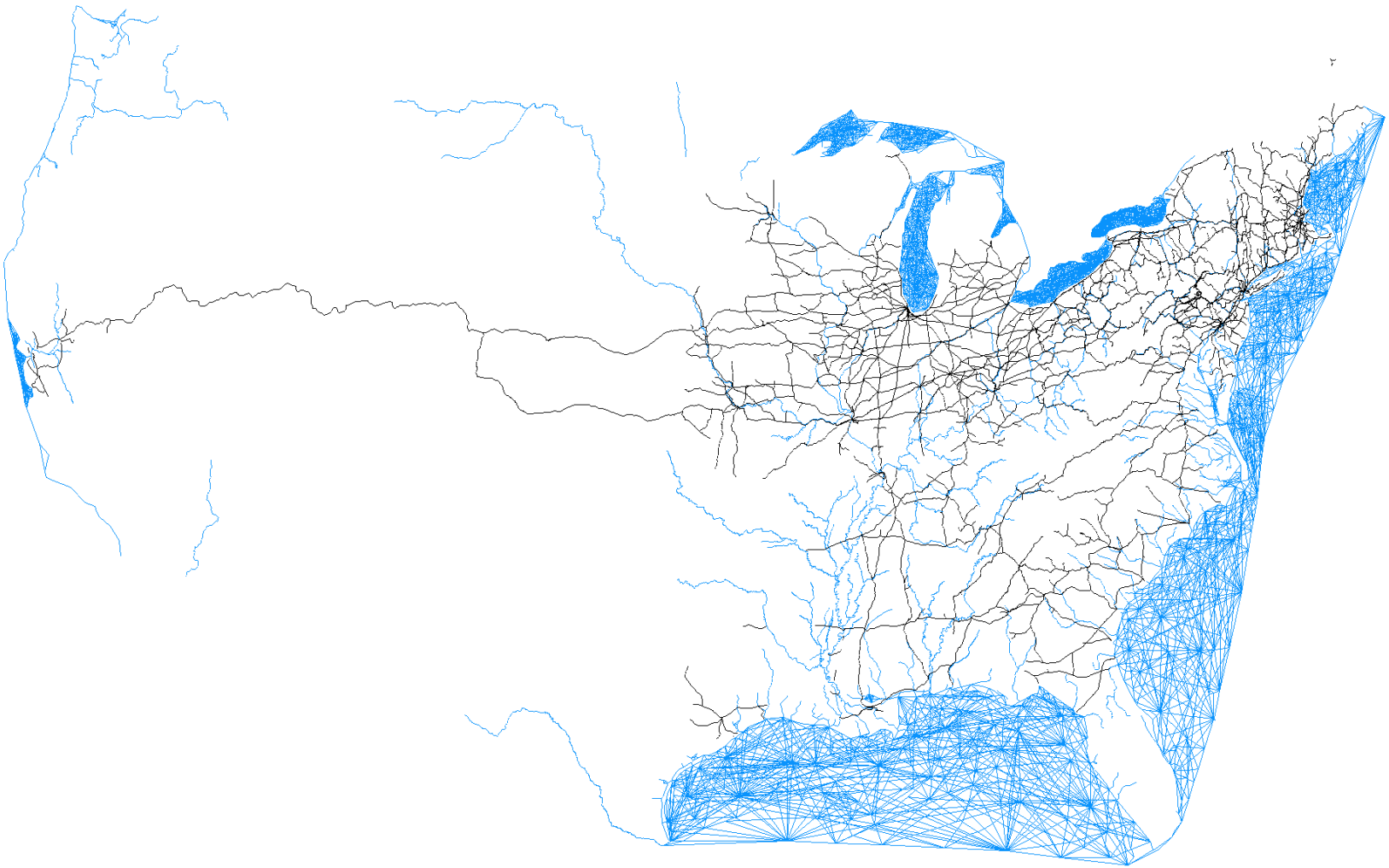
Change in Transportation Network

Waterways and 1860 Railroads



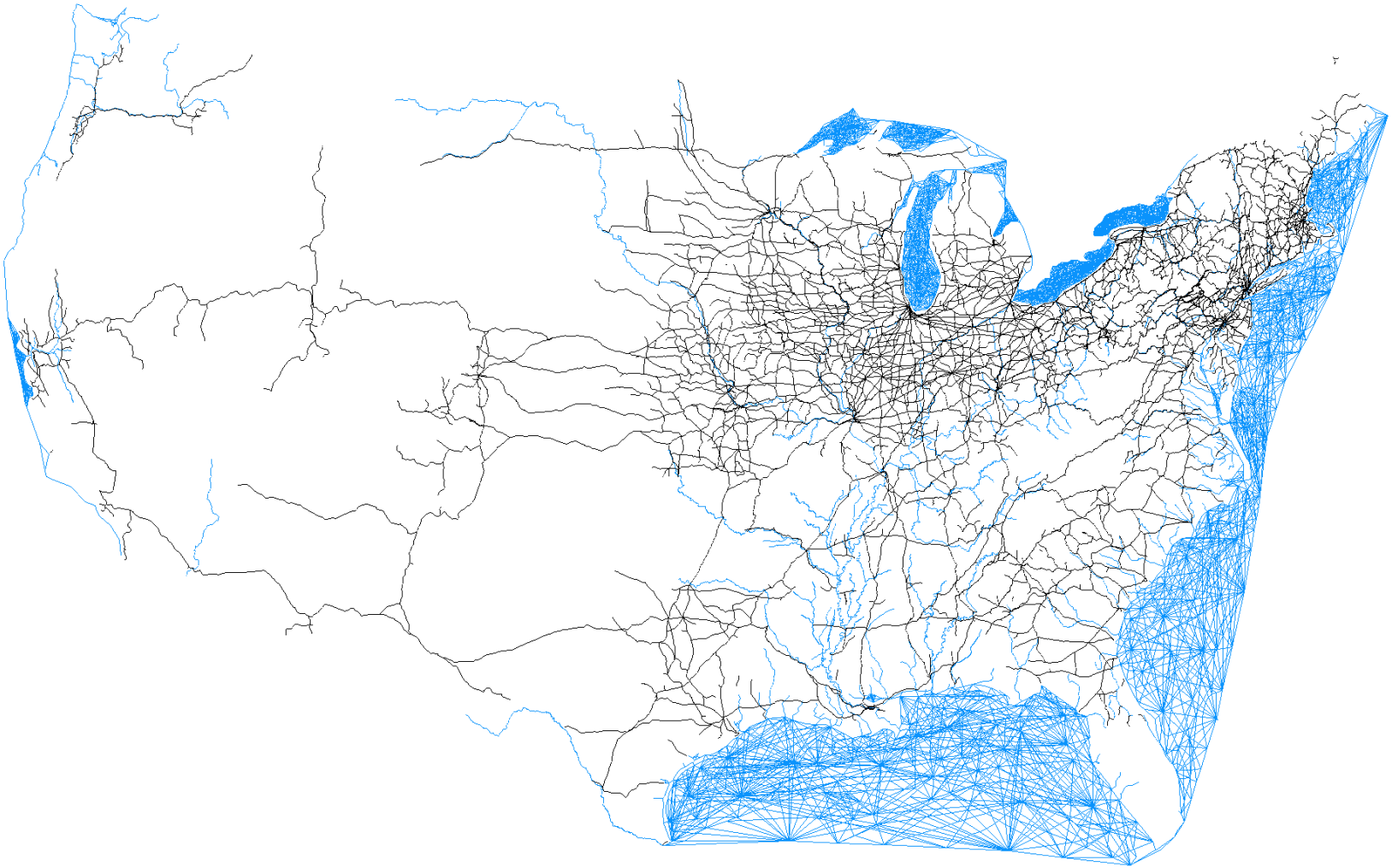
Change in Transportation Network

Waterways and 1870 Railroads



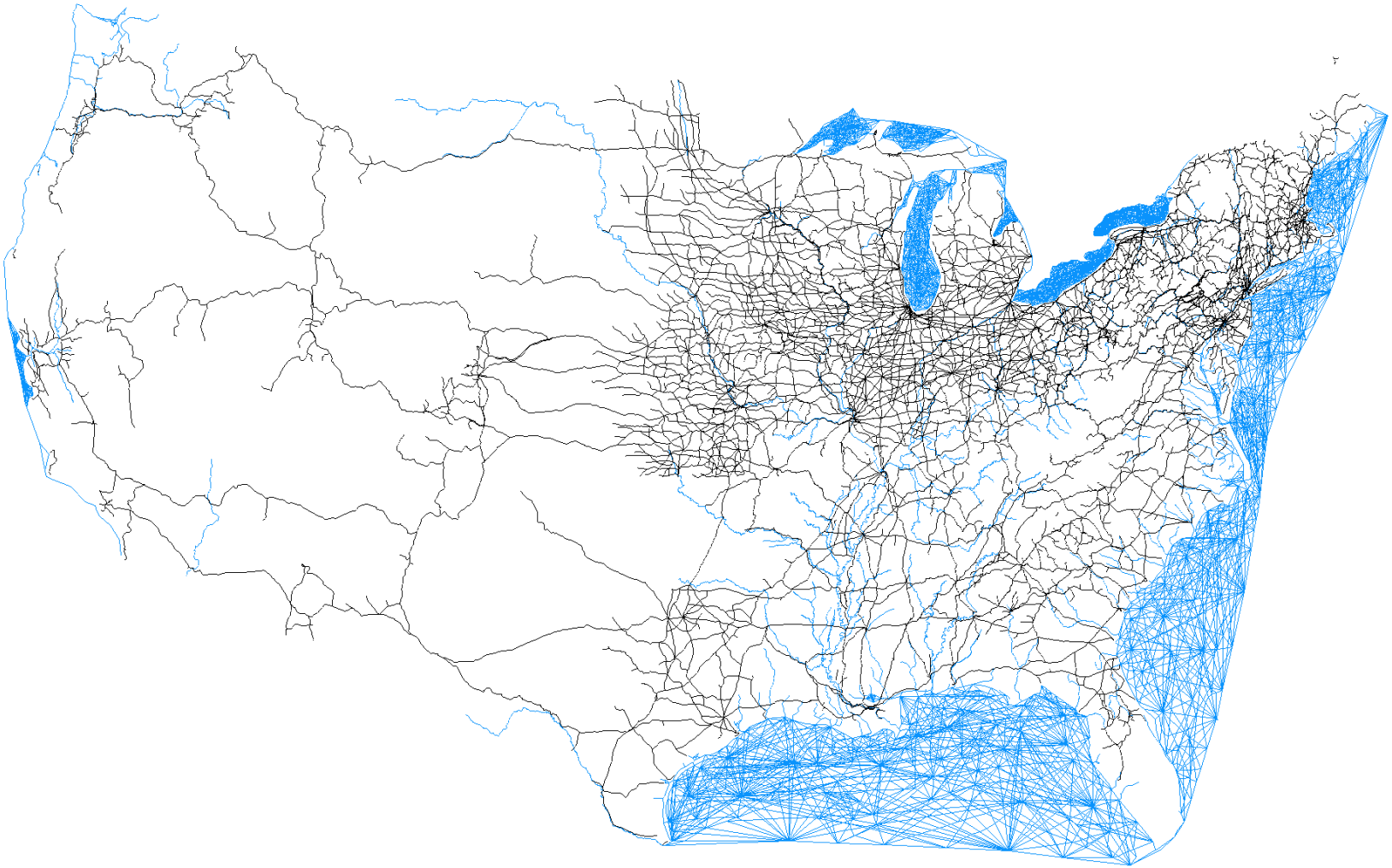
Change in Transportation Network

Waterways and 1880 Railroads



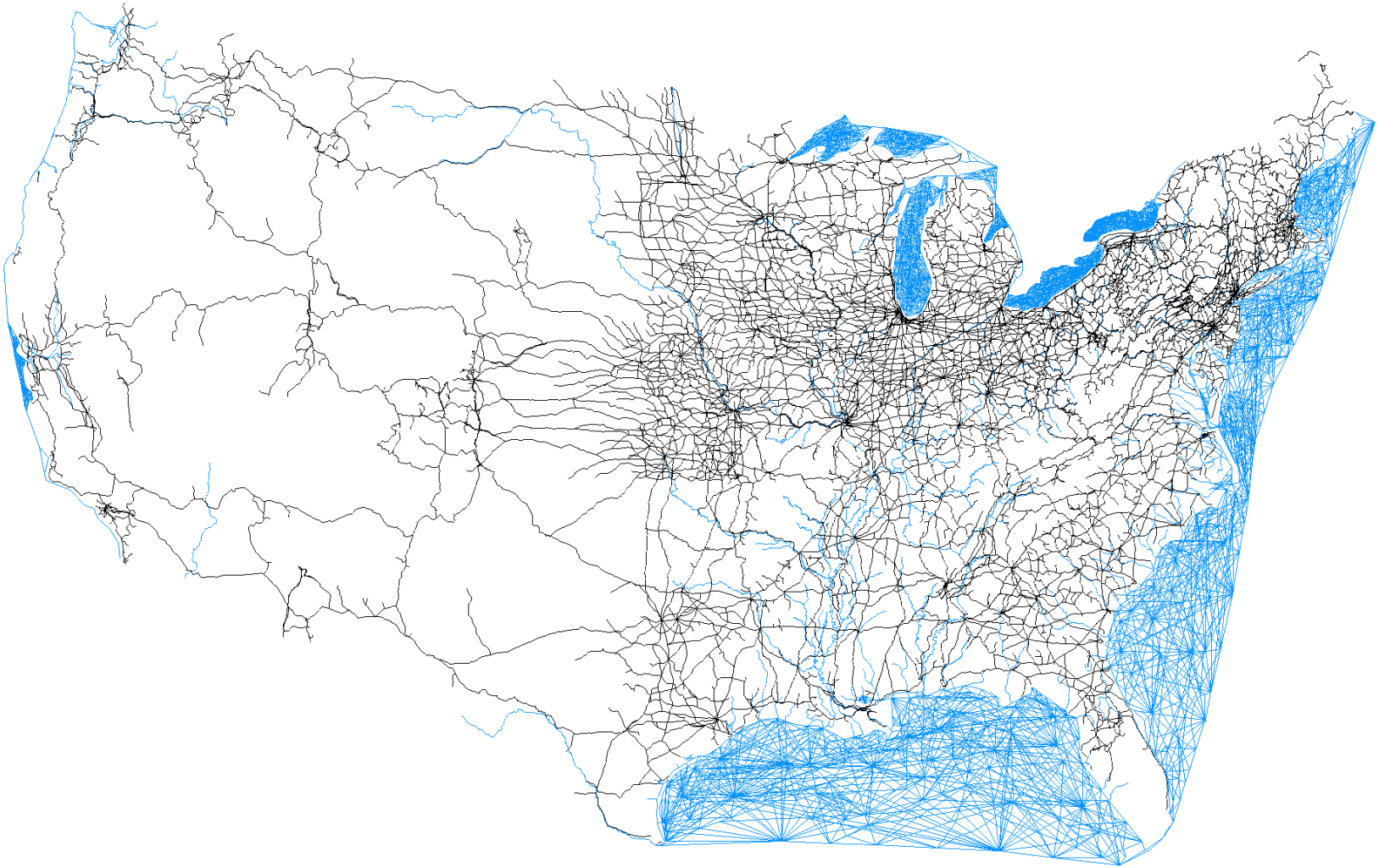
Change in Transportation Network

Waterways and 1890 Railroads



Change in Transportation Network

Waterways and 1900 Railroads



A “Market Access” Approach

Hedonic Method: impacts capitalized in land values

But, the impacts of what?
Railroads are almost everywhere, and affecting everywhere

A “Market Access” Approach

Hedonic Method: impacts capitalized in land values

But, the impacts of what?
Railroads are almost everywhere, and affecting everywhere

Solution: changes in market access (Donaldson and Hornbeck, 2016)

- Mapping transportation routes
- Estimate effects from expansion of RR network, and its removal

A “Market Access” Approach

Hedonic Method: impacts capitalized in land values

But, the impacts of what?
Railroads are almost everywhere, and affecting everywhere

Solution: changes in market access (Donaldson and Hornbeck, 2016)

- Mapping transportation routes
- Estimate effects from expansion of RR network, and its removal

Estimated impact on land values: worth 3.2% of GDP

Opens a path for further analysis

Constructing a Network Database

Network database of transportation modes

- Navigable waterways, time invariant
- Railroad maps, 1860 – 1900
- Wagon routes
- Transshipment points (rail-wagon, rail-water, harbors, etc)

Transportation rates per ton mile (Fogel 1964)

- 0.63 cents for railroads
- 0.49 cents for rivers
- 50 cents for transshipment
- 23.1 cents for wagons

Solve for lowest-cost route between counties c and d in each t

Measuring Railroad Impacts through "Market Access"

Model of supply and demand, with trade costs and factor mobility:

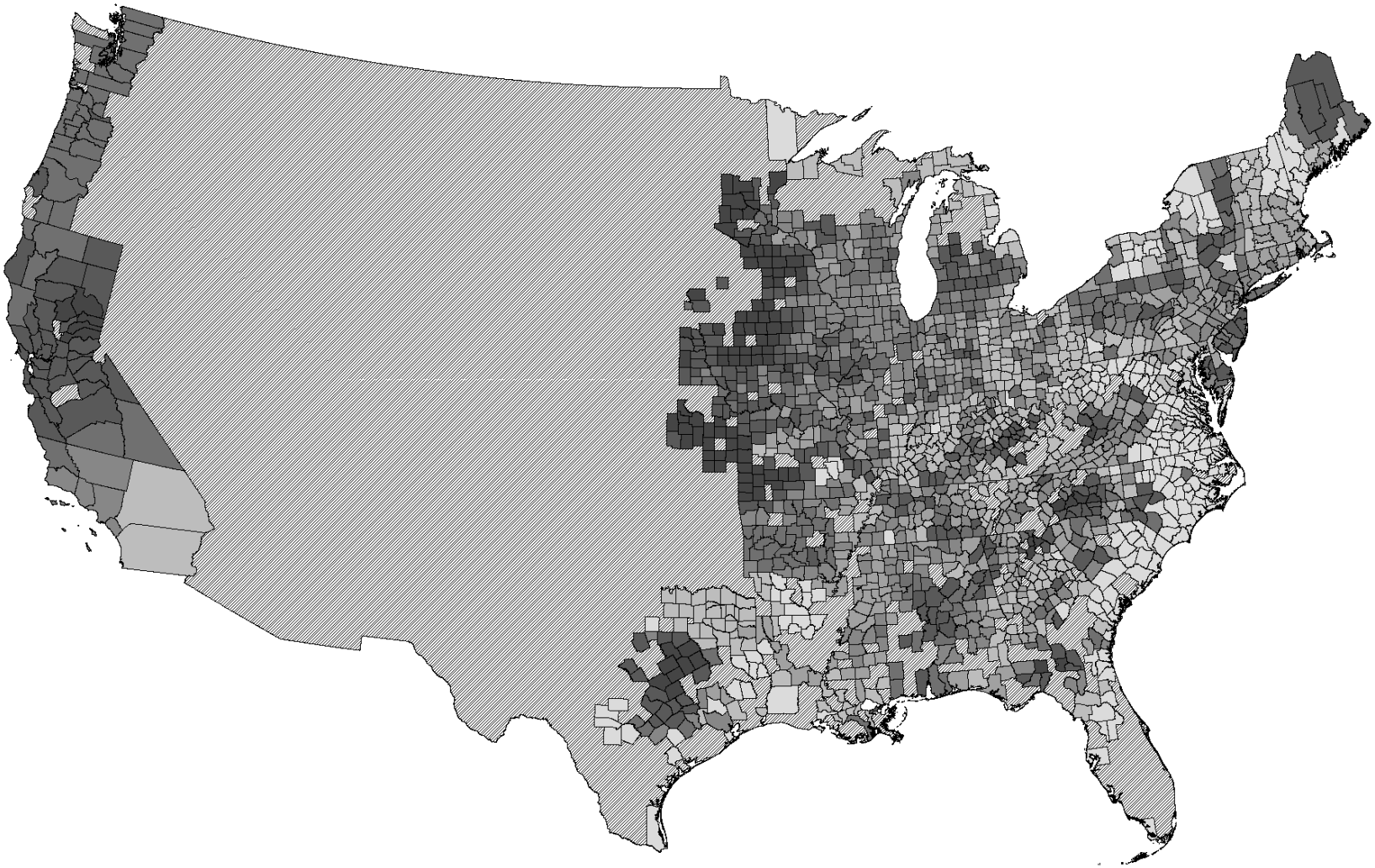
- Consumers have preferences over goods varieties
- Producers have Cobb-Douglas production function for varieties (using labor, capital, land, and materials), with varying productivity and production function elasticities
- Output and Materials costly to trade, iceberg τ
- Capital and Labor freely mobile, r and real wage constant
- Land fixed, rental price is endogenous

Output and input choices impacted by "Market Access:"

- Full version: $MA_c = \sum_d \tau_{cd}^{-\theta} Y_d MA_d^{-1}$
- Approximation: $MA(\mathbf{L})_c = \sum_{d \neq c} \tau_{cd}^{-\theta} L_d$

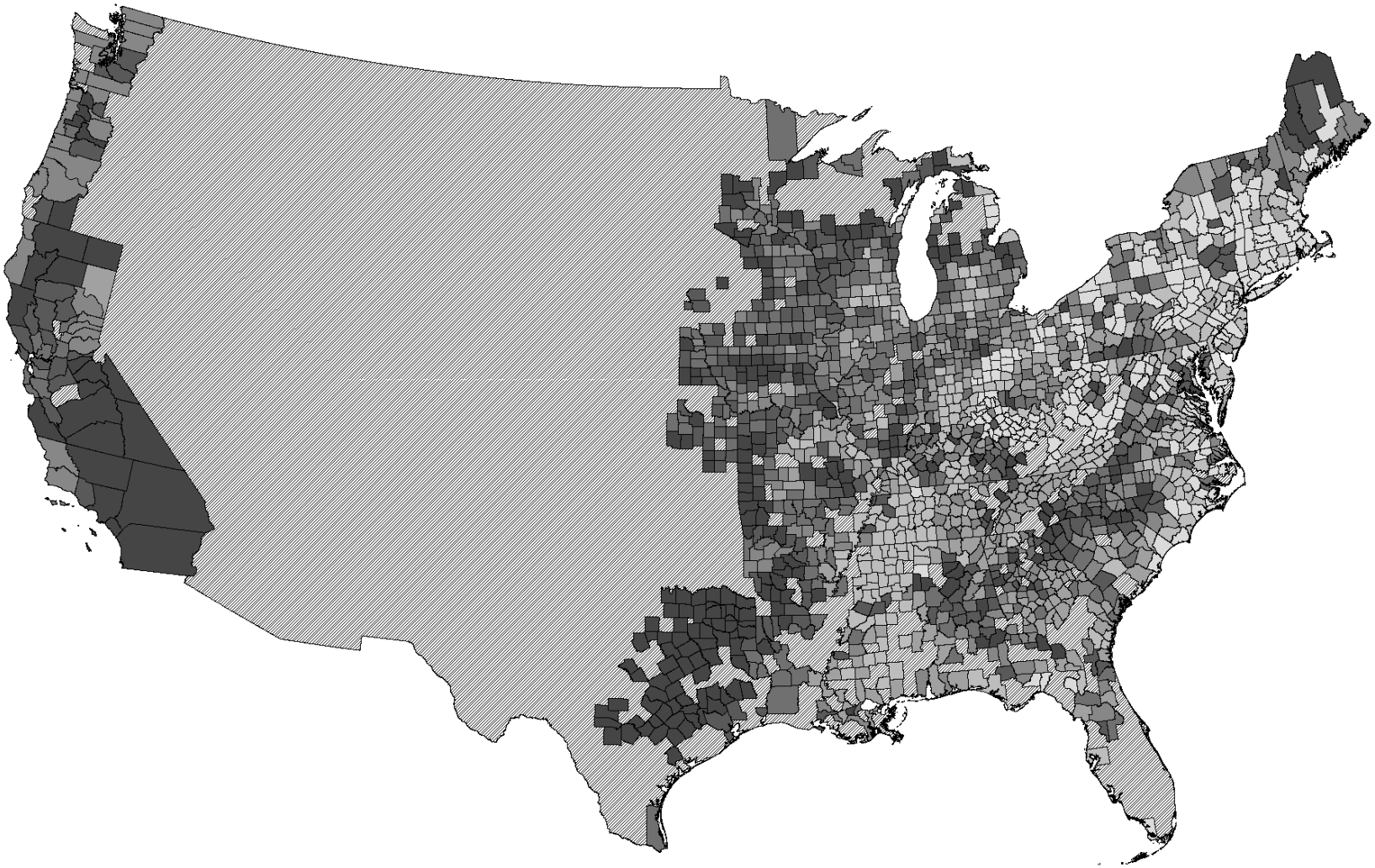
Changes in Log Market Access

1860 to 1870



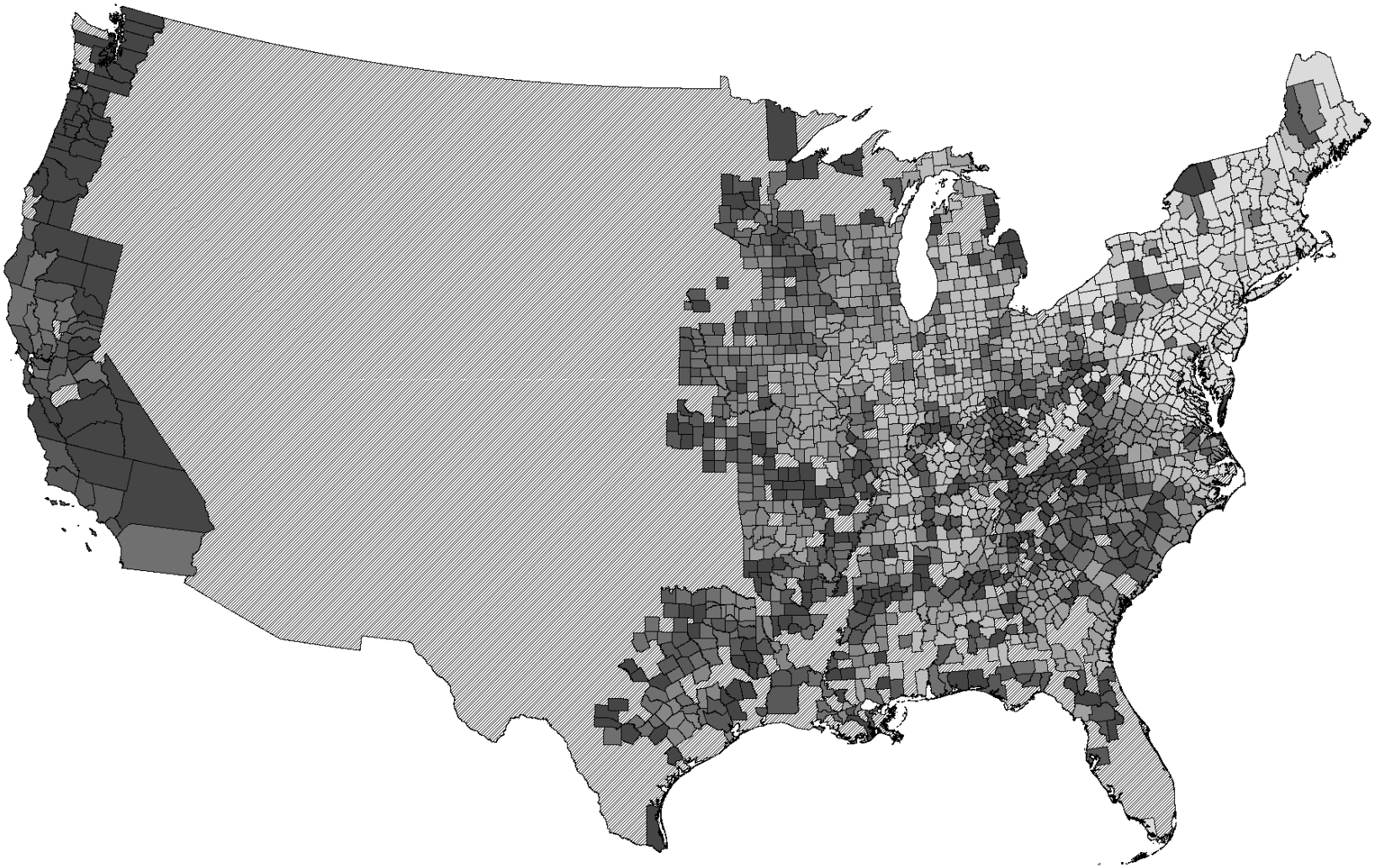
Changes in Log Market Access

1870 to 1880



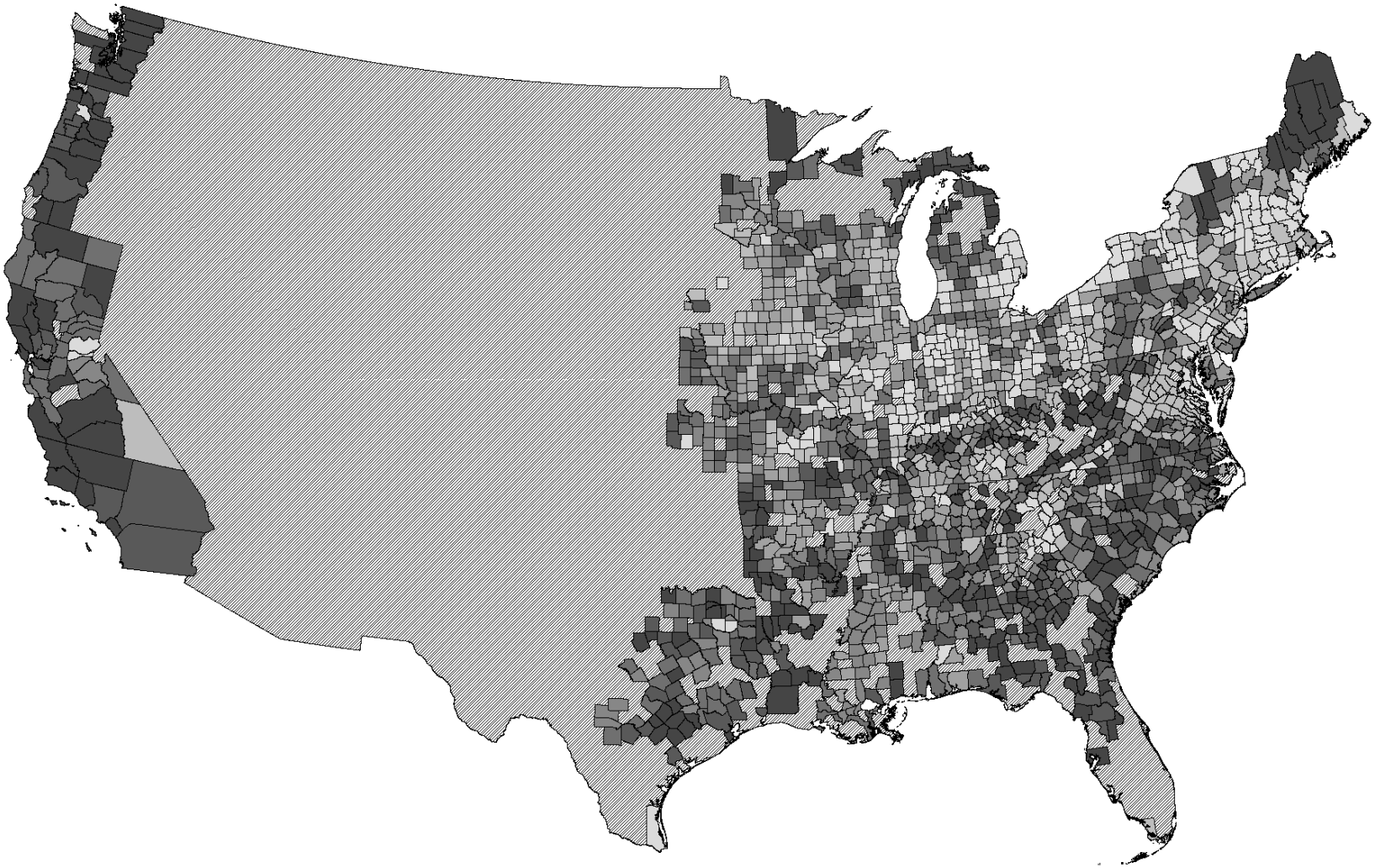
Changes in Log Market Access

1880 to 1890



Changes in Log Market Access

1890 to 1900



Broader Impacts of Market Access

Impacts on land value are only a (small) part of the story

Land is the fixed factor, but surplus is not paid to factors:

- $Pr_c = R_c - \sum_k E_c^k$

How does market integration impact aggregate productivity?

(Hornbeck and Rotemberg, 2024)

Broader Impacts of Market Access

Impacts on land value are only a (small) part of the story

Land is the fixed factor, but surplus is not paid to factors:

- $Pr_c = R_c - \sum_k E_c^k$

How does market integration impact aggregate productivity?

(Hornbeck and Rotemberg, 2024)

Much larger effects:

- Aggregate productivity loss without railroads: 27% of GDP
- Aggregate loss under proposed canal network: 24% of GDP
- 48% social return on railroad capital, 10x the private return

Data from Census of Manufacturers

Digitized county-by-industry tabulations

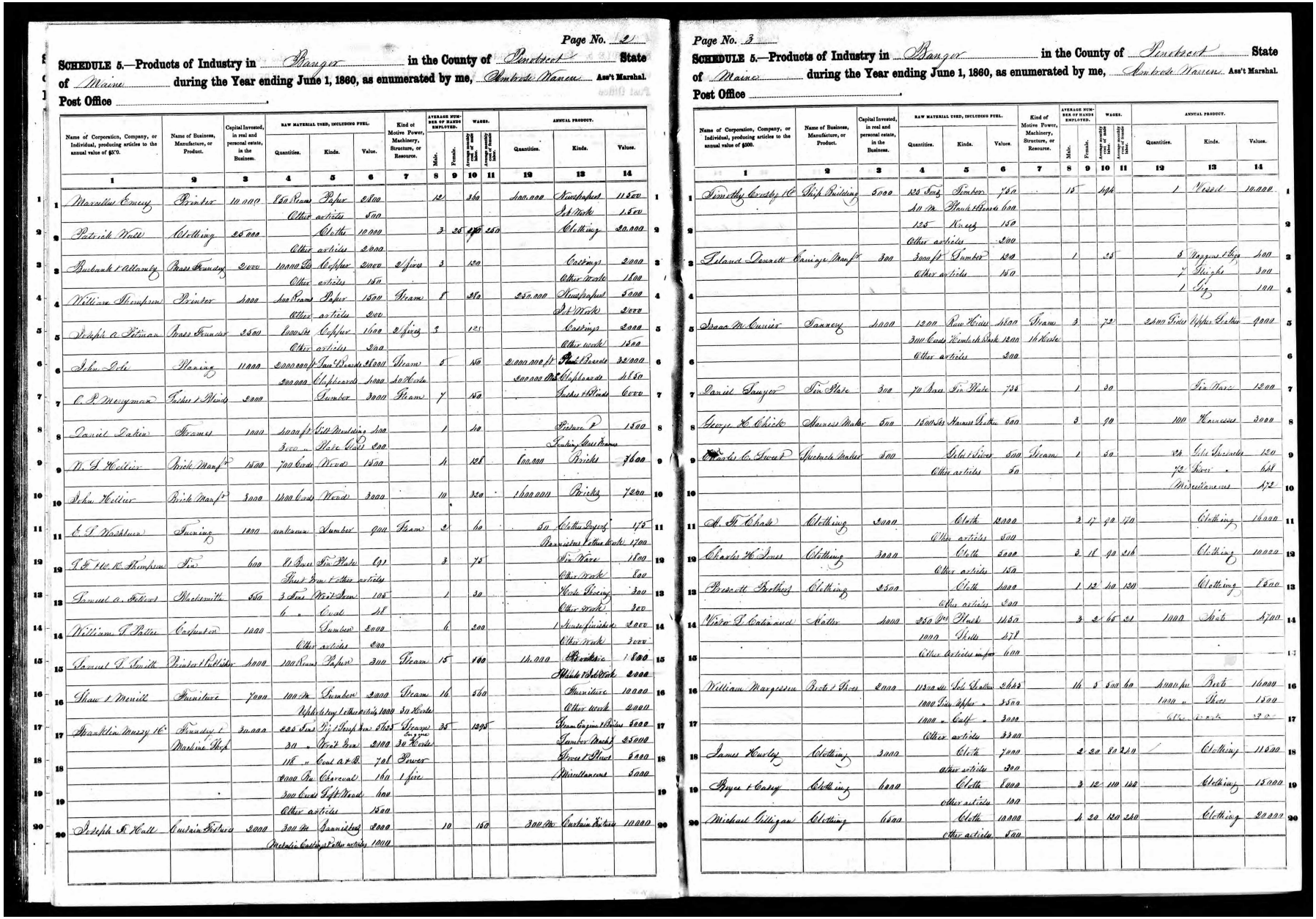
- 1860, 1870, 1880

Value of output, material costs, labor costs, capital stock

County-By-Industry Tables

Counties and industries.	No. of establishments.	Capital.	AVERAGE NUMBER OF HANDS EMPLOYED.			Total amount paid in wages during the year.	Value of materials.	Value of products.
			Males above 16 years.	Females above 15 years.	Children and youths.			
FREDERICK—continued.								
Furniture	16	$34,350	30	.....	1	$6,055	$18,942	$30,598
Iron and steel	2	575,000	200	.....	.....	50,000	112,000	185,000
Leather, curried	8	21,850	9	.....	.....	2,416	25,061	30,420
Leather, tanned	14	101,100	56	.....	1	16,702	140,602	208,857
Lime	12	55,950	95	.....	.....	20,415	36,978	79,090
Liquors, distilled	3	31,000	7	.....	.....	1,780	18,785	29,180
Printing and publishing	5	21,800	49	4	.....	8,850	8,100	28,700
Saddlery and harness	19	21,850	23	.....	3	6,155	27,276	47,391
Sash, doors, and blinds	3	52,000	28	.....	.....	11,541	33,000	48,000
Tinware, copperware, and sheet-iron ware	14	33,381	34	.....	.....	10,100	30,481	58,378
Tobacco, cigars and cigarettes	11	11,800	25	.....	4	6,602	16,714	32,007
GARRETT:								
Flouring- and grist-mill products	12	18,637	10	.....	.....	1,984	26,465	32,535
Lumber, sawed	20	308,750	181	.....	2	45,640	219,237	330,515
Woolen goods	2	6,500	8	3	4	3,075	8,732	20,722
HARFORD:								
Fertilizers	3	40,500	15	.....	1	4,300	32,050	41,550
Flouring- and grist-mill products	41	169,000	55	.....	.....	7,916	252,799	290,364
Fruits and vegetables, canned and preserved	56	186,992	890	603	411	83,155	338,482	535,894
Kaolin and ground earths	5	48,400	44	.....	.....	12,280	8,300	31,060
Lumber, sawed	23	111,150	64	.....	1	12,322	49,842	81,697
Shipbuilding	1	2,000	27	.....	.....	12,700	13,806	28,000
HOWARD:								
Cotton goods	3	574,816	195	213	120	100,418	433,031	738,000
Flouring- and grist-mill products	17	88,200	36	.....	.....	9,514	101,280	124,591
Paper	1	50,000	25	.....	.....	7,000	48,000	60,000
KENT:								
Agricultural implements	12	24,250	33	.....	.....	12,301	9,000	32,342
Fertilizers	2	23,000	16	.....	.....	1,700	14,825	21,050
Flouring- and grist-mill products	9	40,600	15	.....	.....	2,775	68,745	79,559
Fruits and vegetables, canned and preserved	1	22,000	10	115	.....	6,000	3,000	35,000
MONTGOMERY:								
Fertilizers	1	21,000	8	.....	.....	2,200	26,000	31,500
Flouring- and grist-mill products	30	321,550	49	.....	.....	11,111	174,249	202,177
PRINCE GEORGE'S:								
Cotton goods	1	270,000	64	109	28	35,985	141,516	222,031
Flouring- and grist-mill products	15	45,738	24	.....	.....	4,608	54,920	64,465
Iron and steel	1	60,000	190	.....	15	31,300	47,042	80,700
Lumber, sawed	9	16,400	38	.....	.....	7,755	18,002	32,947

Establishment-level Manuscripts



Page No. 2

SCHEDULE 5.—Products of Industry in Bangor in the County of Penobscot State of Maine during the Year ending June 1, 1860, as enumerated by me, Ambrose Warren Ass't Marshal.

Post Office

	Name of Corporation, Company, or Individual, producing articles to the annual value of $500.	Name of Business, Manufacture, or Product.	Capital Invested, in real and personal estate, in the Business.	Raw Material Used, Including Fuel. Quantities.	Kinds.	Value.	Kind of Motive Power, Machinery, Structure, or Resource.	Average Number of Hands Employed. Male.	Female.	Wages. Average monthly wages of Male.	Average monthly wages of Female.	Annual Product. Quantities.	Kinds.	Value.	
1	Marcellus Emery	Printer	10 000	60a Reams	Paper	2500		12		350		300 000	Newspapers	11500	1
				Other articles		500							Job Work	1500	
2	Patrick Neill	Clothing	25 000		Cloths	10 000		3	25	175	250		Clothing	30 000	2
				Other articles		2000									
3	Burbank & Allen 4th	Boots Findings	2400	12000 lbs	Leather	2000	2 fires	3		150			Castings	2000	3
				Other articles		150							Other Work	1500	
4	William Thompson	Printer	5000	5000 Reams	Paper	1500	Steam	8		250		250 000	Newspapers	5000	4
				Other articles		200							Job Work	2000	
5	Joseph A Fellman	Boots Findings	2500	1000 lbs	Leather	1600	2 fires	3		125			Castings	2000	5
				Other articles		200							Other work	1500	
6	John Dole	Planing	11000	2000000 ft	Inch Boards	21000	Steam	5		150		2000000 ft	Plank Boards	32000	6
				200000	Clapboards	5000	10 Horse					500000 No	Clapboards	4150	
7	C P Merryman	Trotters & Blinds	2000		Lumber	3000	Steam	7		150			Trotters & Blinds	6000	7
8	Daniel Baker	Frames	1000	5000 ft	Gilt Moulding	500		1		10			Picture & Looking Glass Frames	1500	8
				3000 "	Plate Glass	200									
9	N. S. Heller	Brick Manf'r	1500	700 Cords	Wood	1500		11		120		600 000	Bricks	7600	9
10	John Heller	Brick Manf'r	3000	1500 Cords	Wood	3000		11		320		1800 000	Bricks	7200	10
11	E. T. Washburn	Turning	1000	100 Cords	Lumber	600	Steam	2		60		50	Clothes Pegs	175	11
													Bannisters Table Work	1700	
12	T. H. & H. K. Hemphill	Tin	600	0 Boxes	Tin Plate	650		3		75			Tin Ware	1500	12
				Sheet Iron & other articles									Other Work	600	
13	Samuel A. Fellows	Blacksmith	550	3 Tons	Wrot Iron	105		1		30			Work Shoeing	300	13
				6 "	Coal	48							Other Work	300	
14	William T. Patten	Carpenter	1000		Lumber	2000		6		200		1	House finished	3000	14
				Other articles		200							Other Work	3000	
15	Samuel D. Smith	Printer & Publisher	5000	100 Reams	Paper	300	Steam	15		100		110 000	Pamphlets	1800	15
													Blank Book Work	2000	
16	Shaw & Merrill	Furniture	7000	100 M	Lumber	2000	Steam	16		550			Furniture	10000	16
				Upholstery & Mirrors		1000	50 Horse						Other work	2000	
17	Franklin Mossy 16	Foundry & Machine Shop	30000	225 Tons	Pig & Scrap Iron	4765	Steam Engine	35		1095			Steam Engines & Boilers	5000	17
				30 "	Wrot Iron	2100	30 Horse						Lumber Sawed	25000	
18				118 "	Coal & Pig	701	Power						Stoves & Plows	5000	18
19				2000 Bu	Charcoal	160	1 fire						Miscellaneous	5000	19
				300 Cwt	Gilt Mouldings	600									
				Other articles		1500									
20	Joseph F. Hall	Curtain Fixtures	2000	300 M	Bannisters	2000		10		150		300 M	Curtain Fixtures	10000	20
				Metallic Castings & other articles		1000									

Page No. 3

SCHEDULE 5.—Products of Industry in Bangor in the County of Penobscot State of Maine during the Year ending June 1, 1860, as enumerated by me, Ambrose Warren Ass't Marshal.

Post Office

	Name of Corporation, Company, or Individual, producing articles to the annual value of $500.	Name of Business, Manufacture, or Product.	Capital Invested, in real and personal estate, in the Business.	Raw Material Used, Including Fuel. Quantities.	Kinds.	Value.	Kind of Motive Power, Machinery, Structure, or Resource.	Average Number of Hands Employed. Male.	Female.	Wages. Average monthly wages of Male.	Average monthly wages of Female.	Annual Product. Quantities.	Kinds.	Value.	
1	Timothy Crosby 16	Ship Building	5000	125 Tons	Timber	750		15		144		1	Vessel	10000	1
				10 M	Plank & Boards	600									
2				125	Knees	150									2
				Other articles		200									
3	Island Durrell	Carriage Manf'r	300	3000 ft	Lumber	120		1		25		3	Wagons & Hays	300	3
				Other articles		180						7	Sleighs	300	
4												1	Jig	100	4
5	Isaac M. Curtis	Tanning	5000	1200	Raw Hides	1800	Steam	3		72		2500 Sides	Upper Leather	9000	5
				3000 Cords	Hemlock Bark	1200	16 Horse								
6				Other articles		200									6
7	Daniel Sawyer	Tin Plate	300	70 Tons	Tin Plate	750		1		30			Tin Ware	1200	7
8	George H. Chick	Harness Maker	500	1500 lbs	Harness Leather	600		3		90		100	Harnesses	3000	8
9	Charles C. Sweet	Spectacle Maker	500		Gold & Silver	600	Steam	1		30		28	Gold Spectacles	120	9
				Other articles		50						72	Silver "	681	
10													Miscellaneous	172	10
11	A. H. Chase	Clothing	3000		Cloth	12000		2	17	90	170		Clothing	18000	11
				Other articles		800									
12	Charles H. Jones	Clothing	3000		Cloth	5000		3	18	90	216		Clothing	10000	12
				Other articles		150									
13	Prescott Brothers	Clothing	2500		Cloth	5000		1	12	50	120		Clothing	7500	13
				Other articles		200									
14	Victor J. Calvinard	Hatter	3000	250 lbs	Wool	1150		3	2	65	21	1000	Hats	3700	14
				1000	Silk	571									
15				Other articles in part		600									15
16	William Margesson	Boots & Shoes	2000	1125 sides	Sole Leather	2625		16	8	500	60	5000 pr	Boots	12000	16
				1000 Calf	Upper "	3500						1000 "	Shoes	1500	
17				1000 "	Calf "	3000						Other work		30	17
				Other articles		3300									
18	James Hurley	Clothing	3000		Cloth	7000		2	20	80	210		Clothing	11500	18
				other articles		300									
19	Joyce & Casey	Clothing	4000		Cloth	7000		3	12	110	150		Clothing	15000	19
				Other articles		100									
20	Michael Gilligan	Clothing	4500		Cloth	12000		4	20	120	280		Clothing	20000	20
				Other articles		500									

Measuring County Productivity

Define county productivity broadly as its aggregate surplus:

- $Pr_c = R_c - \sum_k E_c^k$
- How much output value is not used up by input costs (Solow 1957)

Measuring County Productivity

Define county productivity broadly as its aggregate surplus:

- $Pr_c = R_c - \sum_k E_c^k$
- How much output value is not used up by input costs (Solow 1957)

Impact of market access on log productivity:

- $\frac{\partial \ln Pr_c}{\partial \ln MA} = \left[\frac{\partial R_c \ln R_c}{\partial \ln MA} - \sum_k \frac{E_c \partial \ln E_c^k}{\partial \ln MA} \right] \frac{1}{Pr_c}$
- $\frac{\partial \ln Pr_c}{\partial \ln MA} = \left[\frac{\partial \ln R_c}{\partial \ln MA} - \sum_k s_c^k \frac{\partial \ln E_c^k}{\partial \ln MA} \right] \frac{R_c}{Pr_c}$
- s_c^k is the revenue share of input k

Measuring County Productivity

Define county productivity broadly as its aggregate surplus:

- $Pr_c = R_c - \sum_k E_c^k$
- How much output value is not used up by input costs (Solow 1957)

Impact of market access on log productivity:

- $\frac{\partial \ln Pr_c}{\partial \ln MA} = \left[\frac{\partial R_c \ln R_c}{\partial \ln MA} - \sum_k \frac{E_c \partial \ln E_c^k}{\partial \ln MA} \right] \frac{1}{Pr_c}$
- $\frac{\partial \ln Pr_c}{\partial \ln MA} = \left[\frac{\partial \ln R_c}{\partial \ln MA} - \sum_k s_c^k \frac{\partial \ln E_c^k}{\partial \ln MA} \right] \frac{R_c}{Pr_c}$
- s_c^k is the revenue share of input k

Impact can be decomposed into two components (TFPR and AE):

$$\frac{\partial \ln Pr_c}{\partial \ln MA} = \left(\left[\frac{\partial \ln R_c}{\partial \ln MA} - \sum_k \alpha_c^k \frac{\partial \ln E_c^k}{\partial \ln MA} \right] + \left[\sum_k (\alpha_c^k - s_c^k) \frac{\partial \ln E_c^k}{\partial \ln MA} \right] \right) \frac{R_c}{Pr_c}$$

Measuring County Productivity

Define county productivity broadly as its aggregate surplus:

- $Pr_c = R_c - \sum_k E_c^k$
- How much output value is not used up by input costs (Solow 1957)

Impact of market access on log productivity:

- $\frac{\partial \ln Pr_c}{\partial \ln MA} = \left[\frac{\partial R_c \ln R_c}{\partial \ln MA} - \sum_k \frac{E_c \partial \ln E_c^k}{\partial \ln MA} \right] \frac{1}{Pr_c}$
- $\frac{\partial \ln Pr_c}{\partial \ln MA} = \left[\frac{\partial \ln R_c}{\partial \ln MA} - \sum_k s_c^k \frac{\partial \ln E_c^k}{\partial \ln MA} \right] \frac{R_c}{Pr_c}$
- s_c^k is the revenue share of input k

Impact can be decomposed into two components (TFPR and AE):

$$\frac{\partial \ln Pr_c}{\partial \ln MA} = \left(\left[\frac{\partial \ln R_c}{\partial \ln MA} - \sum_k \alpha_c^k \frac{\partial \ln E_c^k}{\partial \ln MA} \right] + \left[\sum_k (\alpha_c^k - s_c^k) \frac{\partial \ln E_c^k}{\partial \ln MA} \right] \right) \frac{R_c}{Pr_c}$$

County input gaps: $(\alpha_c^k - s_c^k)$

- Reflect value marginal products greater than marginal costs
- Markups, input frictions, other distortions

Estimated Growth in Productivity

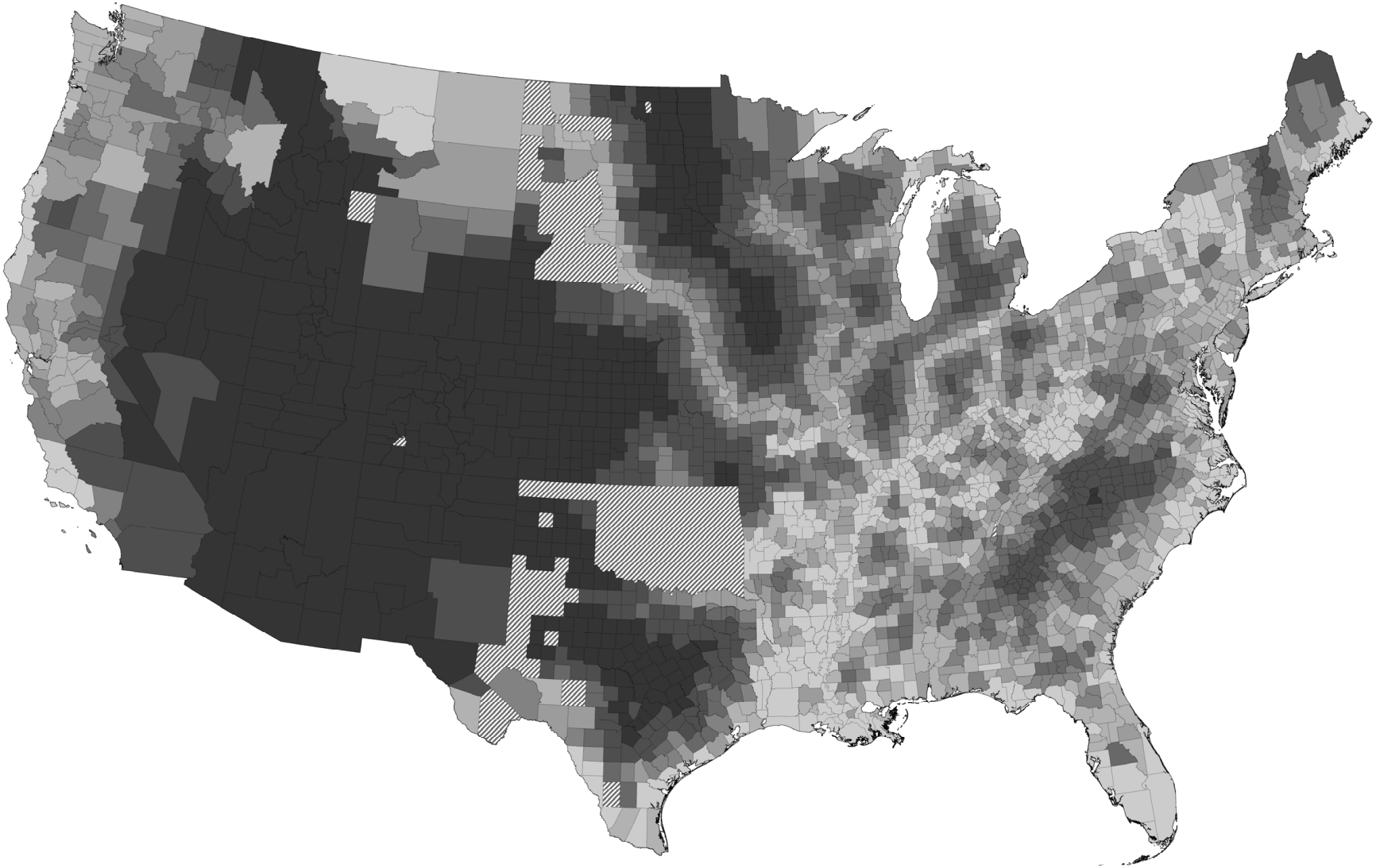
Substantial estimated relative impacts on productivity:

- From 1860 to 1880, 1 s.d. greater increase in market access increased manufacturing productivity by 20%
- Effect driven by county AE, little change in county TFPR
- Insensitive to controls for local railroad construction

Little impact of MA on input gaps, but:

- Increased MA induced general expansion in economic activity, in the presence of distortions
- Shifted inputs to places with greater distortions
  - Leon Moses: location matters
- Increased aggregate input-use

Figure 4. Counterfactual Changes in Market Access, by County



Appendix Figure 9. County-level Gaps in the Counterfactual Analysis

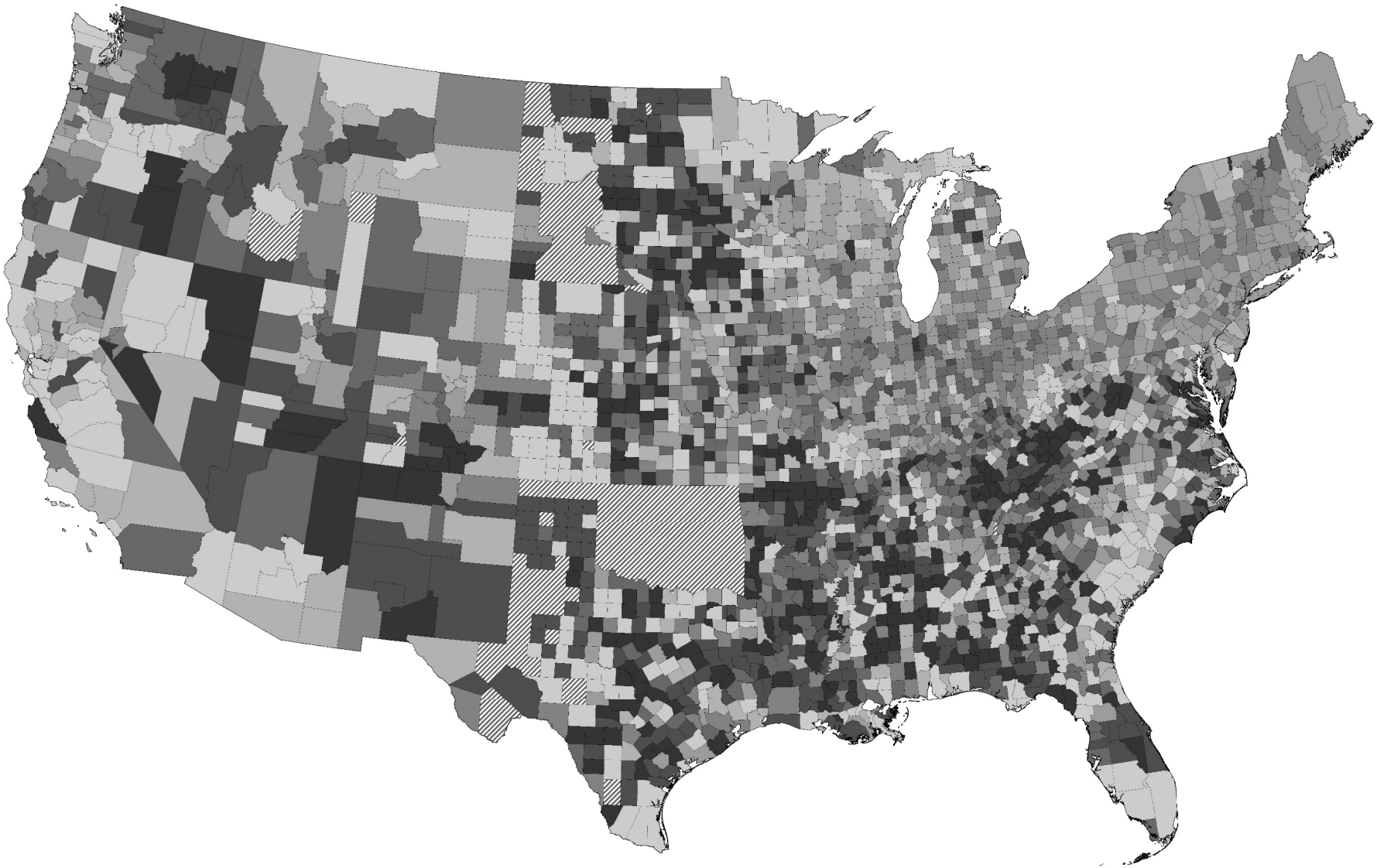
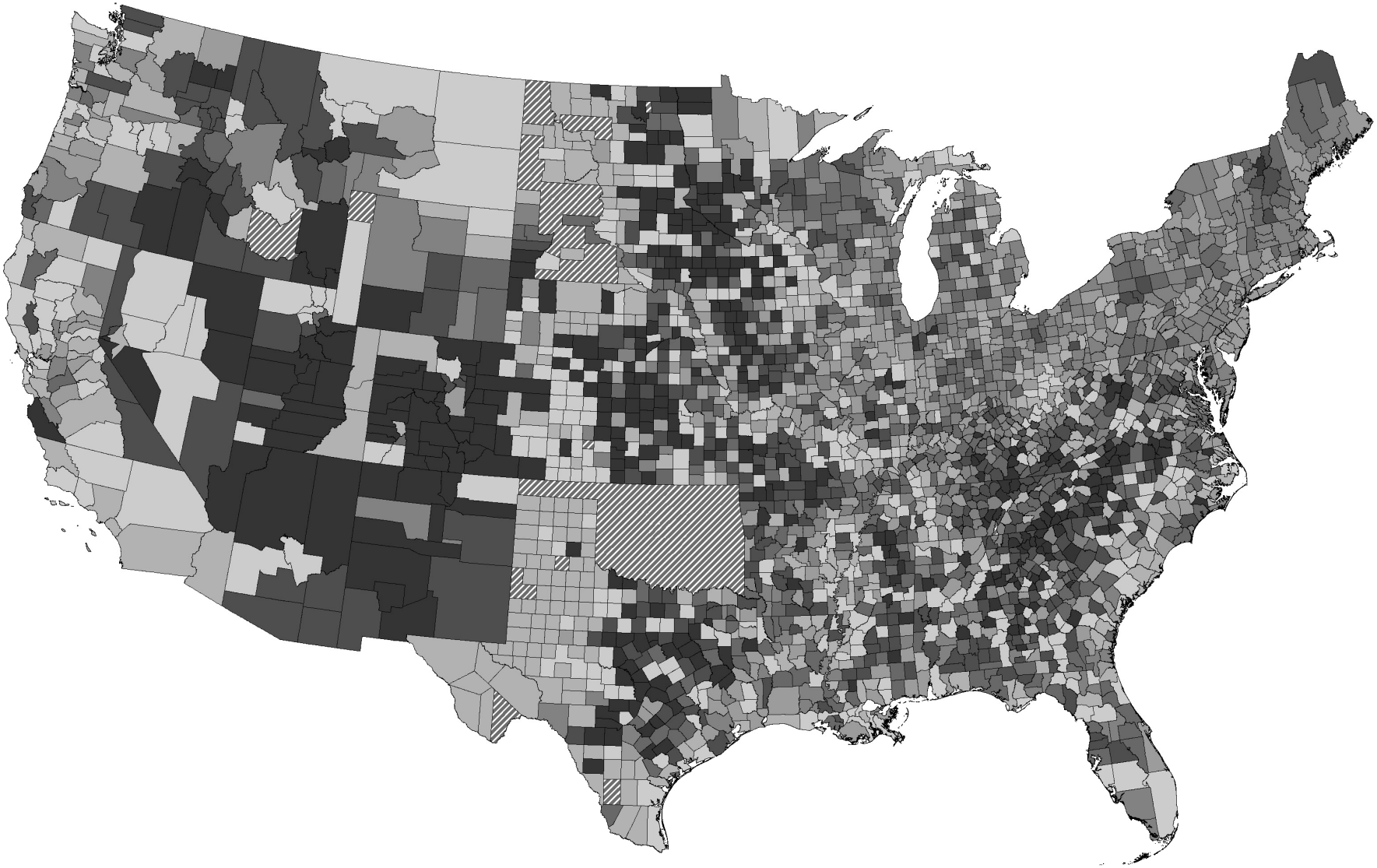


Figure 5. Counterfactual Changes in Productivity, by County



Why Such Large Effects?

Large impacts driven by factor misallocation

- Increased inputs in marginally productive counties (where value marginal product exceeds marginal cost)
- Historical inefficiencies not especially high: less than modern US, modern developing countries

Why Such Large Effects?

Large impacts driven by factor misallocation

- Increased inputs in marginally productive counties (where value marginal product exceeds marginal cost)
- Historical inefficiencies not especially high: less than modern US, modern developing countries

When resources are allocated inefficiently, widely-used infrastructure/technologies have substantially larger economic benefits

Why Such Large Effects?

Large impacts driven by factor misallocation

- Increased inputs in marginally productive counties (where value marginal product exceeds marginal cost)
- Historical inefficiencies not especially high: less than modern US, modern developing countries

When resources are allocated inefficiently, widely-used infrastructure/technologies have substantially larger economic benefits

Hard: make places more efficient
Easy: expand activity in places that are inefficient

Why Such Large Effects?

Large impacts driven by factor misallocation

- Increased inputs in marginally productive counties (where value marginal product exceeds marginal cost)
- Historical inefficiencies not especially high: less than modern US, modern developing countries

When resources are allocated inefficiently, widely-used infrastructure/technologies have substantially larger economic benefits

Hard: make places more efficient
Easy: expand activity in places that are inefficient

Hard: increase aggregate productivity through TFP growth

(Mokyr: “Lever of Riches” and “Gifts from Athena”)

Easy: increase aggregate productivity through greater input-use

In Sum

Substantial productivity impacts from market access (and railroads)

- Key: presence of misallocation
- Social savings are not a meaningful upper bound
- Land values miss substantial economic gains

Reducing inefficiencies is good, but:

- Increased inputs generates much larger economic gains in the presence of market inefficiencies
- With great problems come great possibilities

Future: establishment-level data, with values and quantities

- Agenda on causes and consequences of productivity growth
- Website launched today: CMFdata.org