Roads, Railways and Decentralization of Chinese Cities

September, 2012

Nathaniel Baum-Snow, Brown University

Loren Brandt, University of Toronto

J. Vernon Henderson, Brown University

Matthew A. Turner, University of Toronto

and

Qinghua Zhang, Guanghua School of Business, Peking University

Goals of the Paper

- Understand the forces driving urban spatial form in a developing country context
- Specifically:
  - Estimate the effects of **highway** and **rail** networks on decentralization in Chinese cities since 1990
    - Various configurations: **radial rays, rings, total kilometers of network**
  - Examine effects of transport infrastructure on decentralization of:
    - population
    - industrial GDP and total GDP
  - Find instruments from early planning era that have validity and allow identification of causal effects

Motivations

- World Bank: about 20% of lending to transport infrastructure (more than social lending)

- Huge investments: China: $200b (2007) in infrastructure investments per year. Much in cities
  - Shapes cities for decades/centuries to come

- Little known about impacts in developing countries
- Mayors/planners:

(1) Optimal configurations: transit, radial and ring highways?

(2) Impact of specific types of investments?
  - Chinese experiences more likely to be policy relevant in other LDC's, than evidence from the United States

Motivations

1. **Compact cities (vs. sprawl)**
   - Investments affect spread: lower commuting, rents, density
     - Versus: "Green cities": energy and the environment **("fundamental law")**
     - Chinese perspective: Use of ex-urban farm land: "food security"
2. **Spatial (re-) organization of industry for economic growth**
   - How best use information rich environments of central cities?
   - Early on: industrialization of central cities
     - Maoist plan but has real reasons
       - Rich information environment: import & adapt foreign technologies
       - Better infrastructure and institutional development
   - Later: industry decentralizes (Duranton & Puga, 2001)
     - Cheaper land and labor.
     - Central cities: professional and business service centers
3. **Facilitation of Urbanization, Promoting National Economic Growth**

Relationship to Existing Literature

- Literature on **transport infrastructure**
  - For LDC's : the first look within cities
    - vs. Faber (2010); Donaldson (2012); Banerjee, Duflo, Qian (2012)
  - Effects of Transport on US Cities
    - Baum-Snow 2007, Duranton and Turner 2011
    - Our study:
      - **Innovation is not the IV strategy**
      - **Comprehensive look**
      1. Rich set of transport infrastructure: rails & rings, as well as highway rays (public transport, canals)
      2. Rich set of outcomes: GDP, industrial GDP, population
- Literature on **industrial decentralization**
  - Hansen 1987, Lee and Choe 1990, Henderson Kuncoro and Nasution 1996
  - Case studies only
- More complete and systematic data on outcomes and transport infrastructure than has been explored elsewhere

Preview of Results

- **Highway rays**
  - Each additional radial highway displaced about 4.0 percent of central city **population** to suburban regions
  - **No affect on industrial decentralization (yet)**
- **Highway kms**
  - No effect conditional on rays
- **Railroad rays**
  - Each railroad ray displaced 26 percent of industrial GDP from the central city to suburbs
  - **No effect on population**
- **Ring roads in "suburbs"**
  - Decentralization of both population and GDP
    - Feed to highway and rail rays
- **Buses and trolleys** in central city retard decentralization

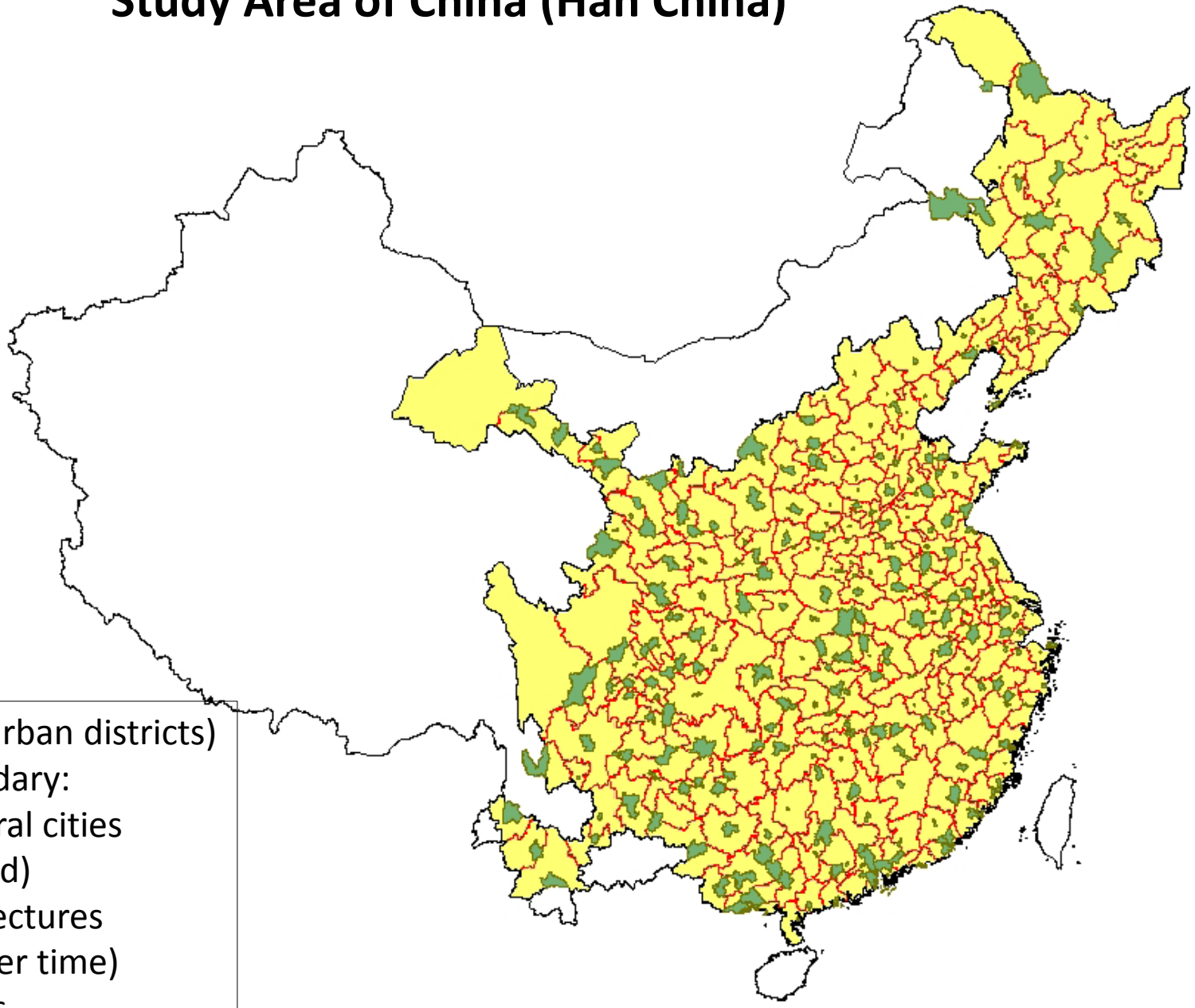
Context

- 1990 **central cities** ("city proper" in 1990) for 2005 **prefectures**
  - for urbanized prefectures in Han China
- After 1990, big within prefecture movements of rural populations into central cities (urbanization).
  - Migration from outside the prefecture limited by hukou system
- Over 10% annual growth in real GDP per capita
  - Huge increases in demand for housing
- In 1990 no limited access highways in China
  - Little commuting
- Goods shipped by rail (5% of ton-kms by "highway" in 1990)

Context

- Urban reform in early 1990's: create "land market" and move industry to market basis.
- Couldn't really decentralize before 1990: rural vs. urban
- Reforms:
  - Start to separate living from work place: start of commuting
    - Limited cars and no scooters in urban districts
  - Factories sell off land and move to ex-urban areas; FDI
- 1990 cities not recognizable today

Study Area of China (Han China)

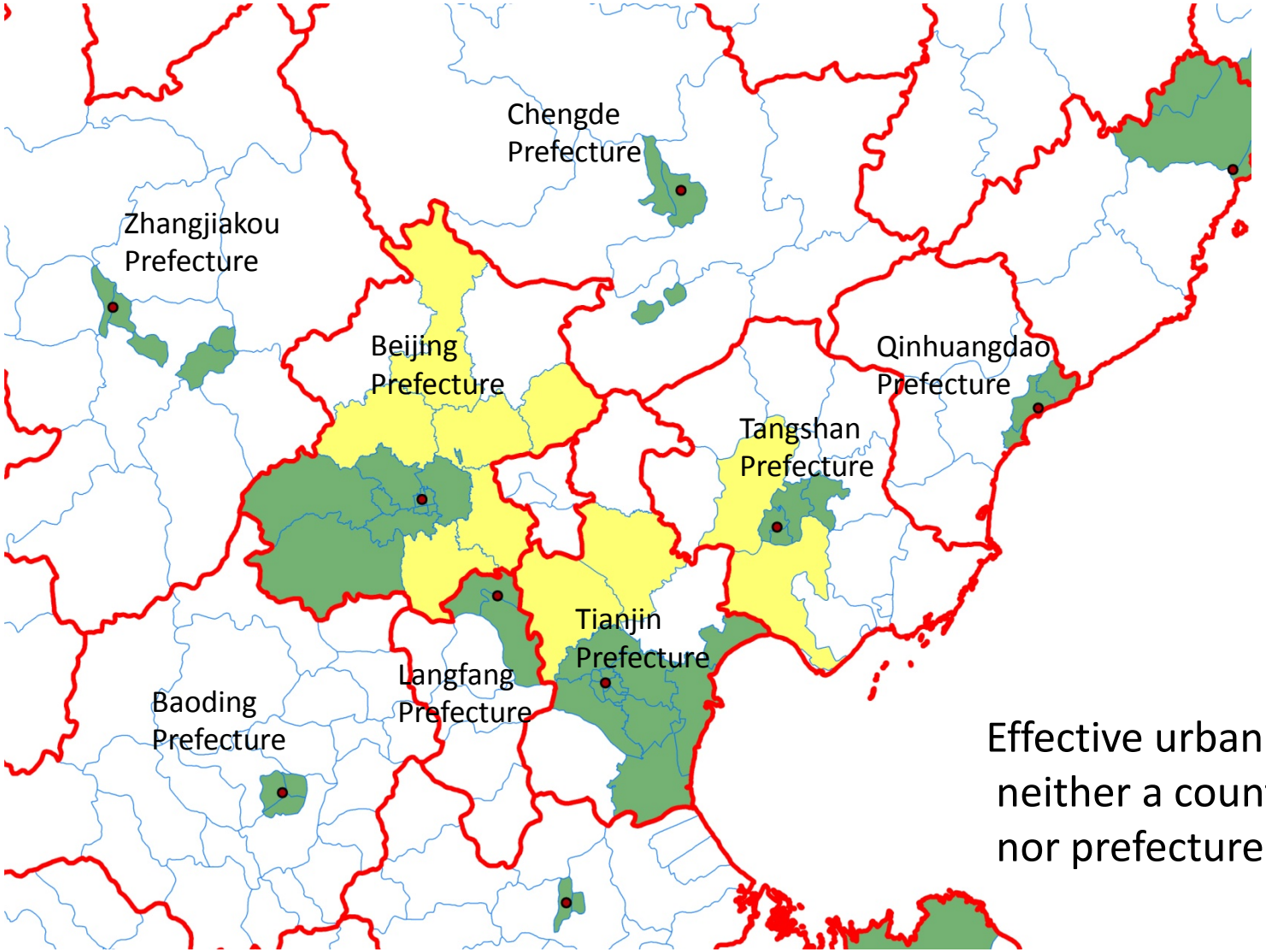


- Use counties (urban districts)
- Constant boundary:
  - 1990 central cities (expand)
  - 2005 prefectures (changes over time)
- Promoted cities

Geography and Outcomes Data

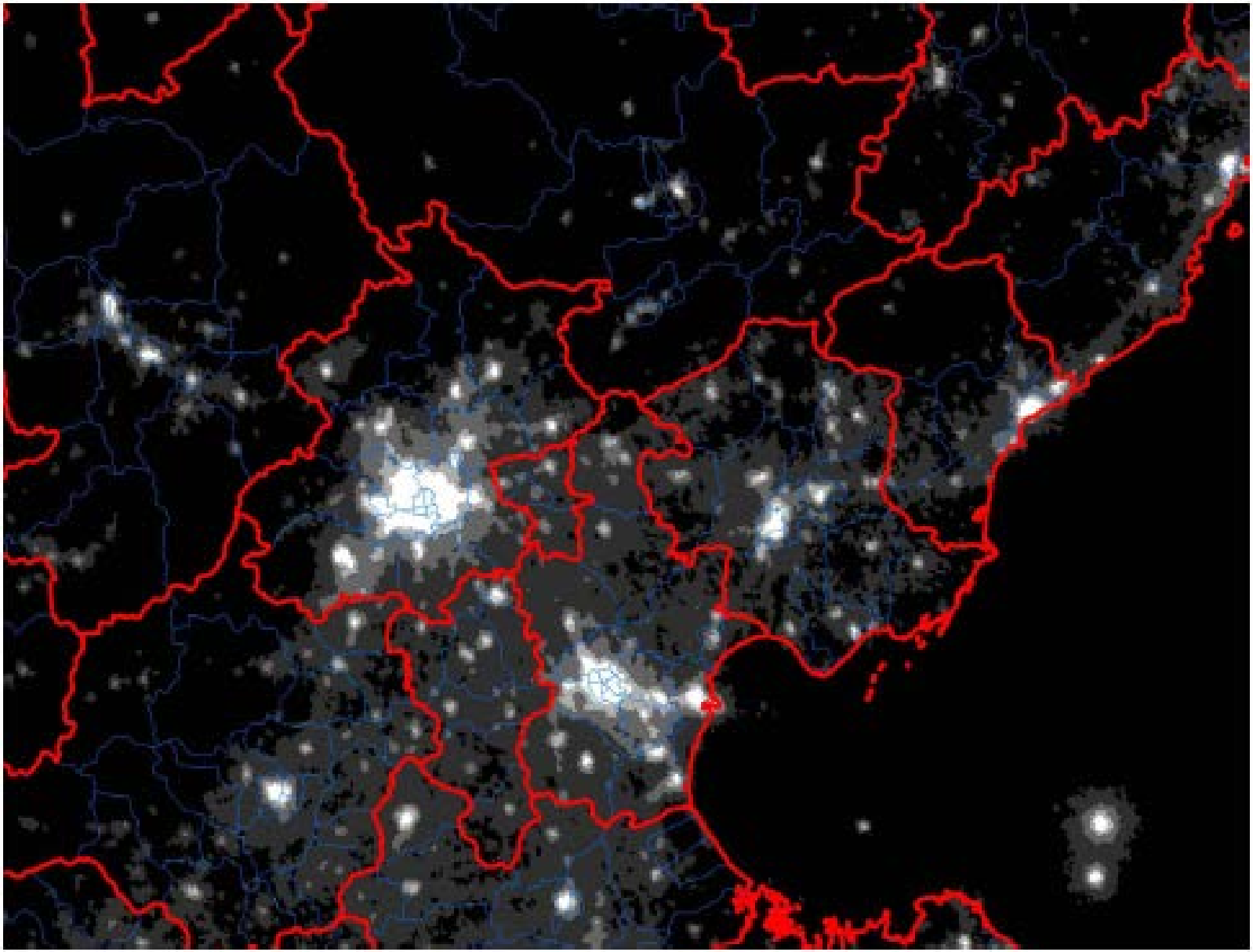
- 1990 definition core cities of prefectures and prefectures as of 2005 are the primary spatial units of analysis
  - Goal is to choose city geographies that do not respond to infrastructure built 1990-2010
  - 70 of 257 cities in the analysis had boundary changes 1990-2010
  - Exclude prefectures with no defined core city
- Information on population comes from 100% count censuses in 1990, 2000 & 2010
  - Only have information for 210 prefectures in 2010
- Information on GDP comes from various printed yearbooks and Michigan Online
  - Only have information for 205 core cities in 1990
  - Supplement with lights at night data to reduce selection concerns

Beijing Area

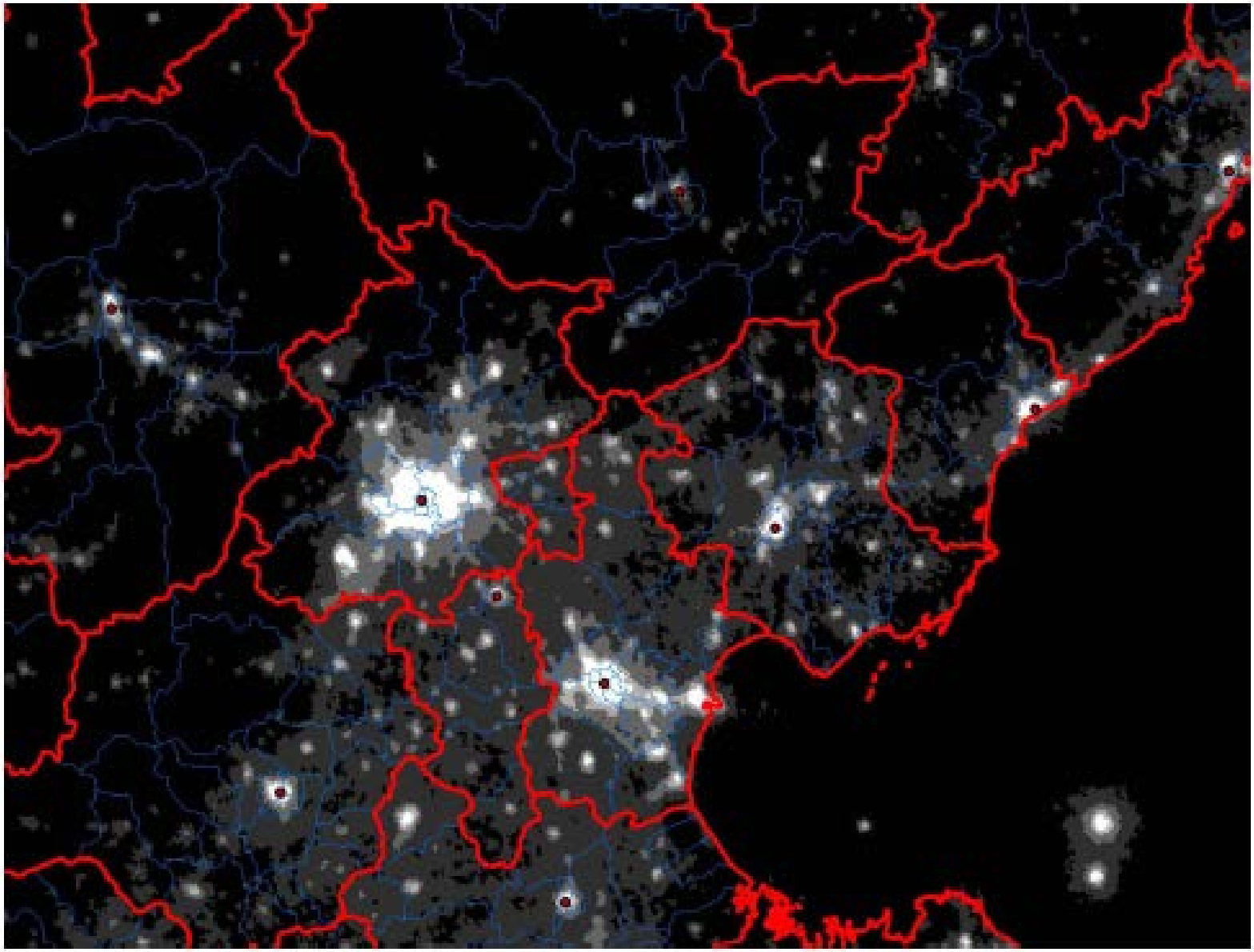


Effective urban area is
neither a county
nor prefecture

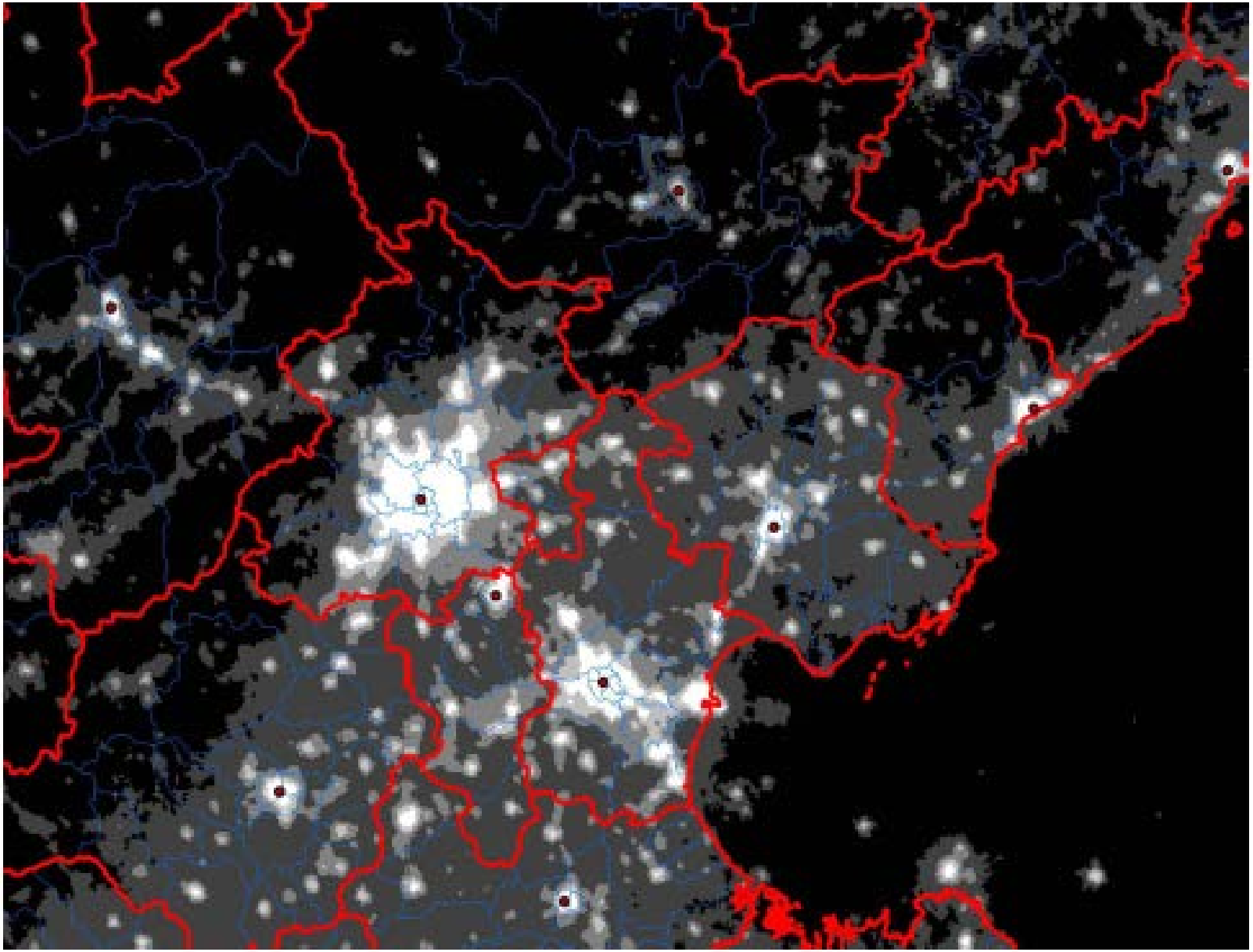
Lights at Night in 1992



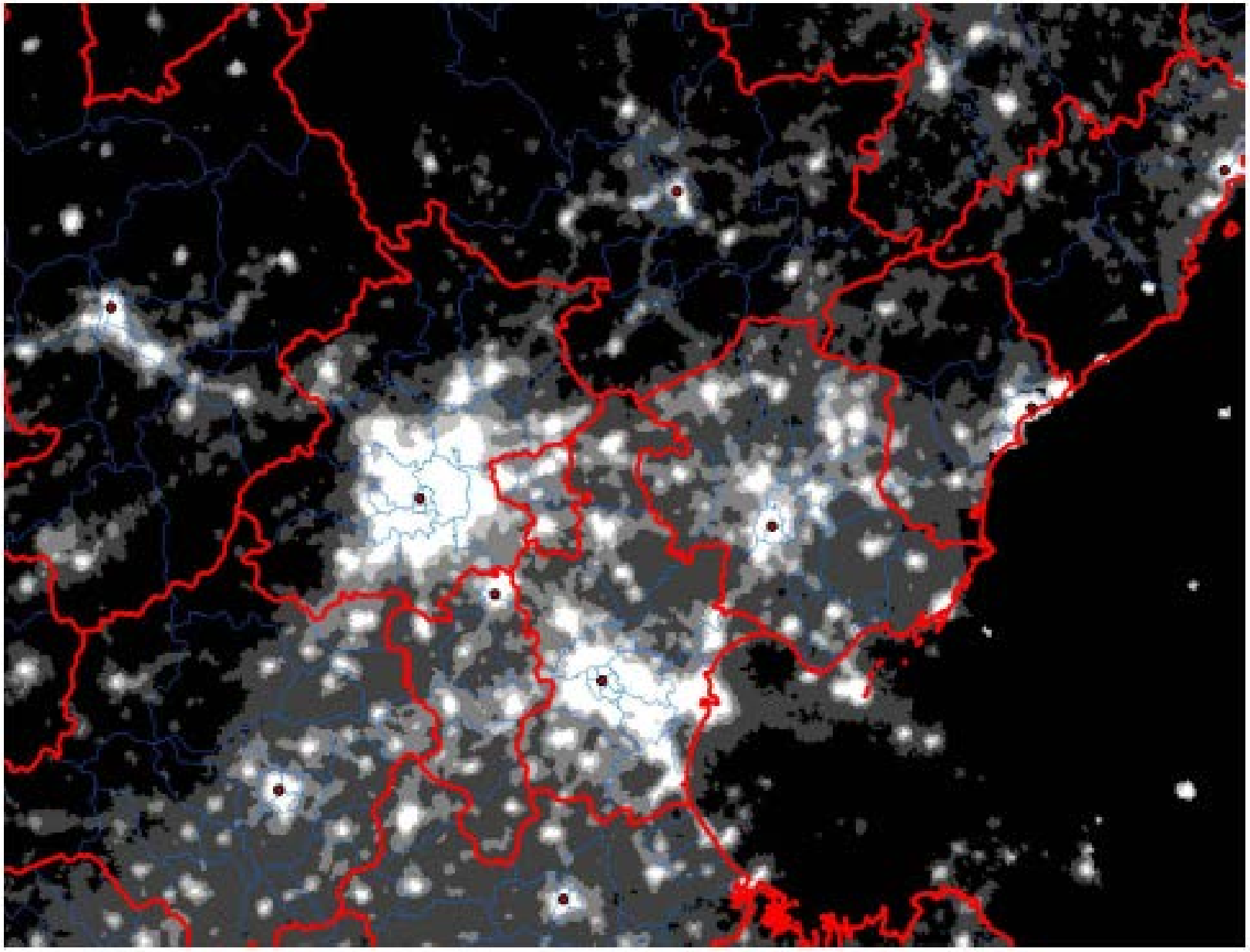
Determining CBD Locations (Brightest cell)



Lights at Night in 2000



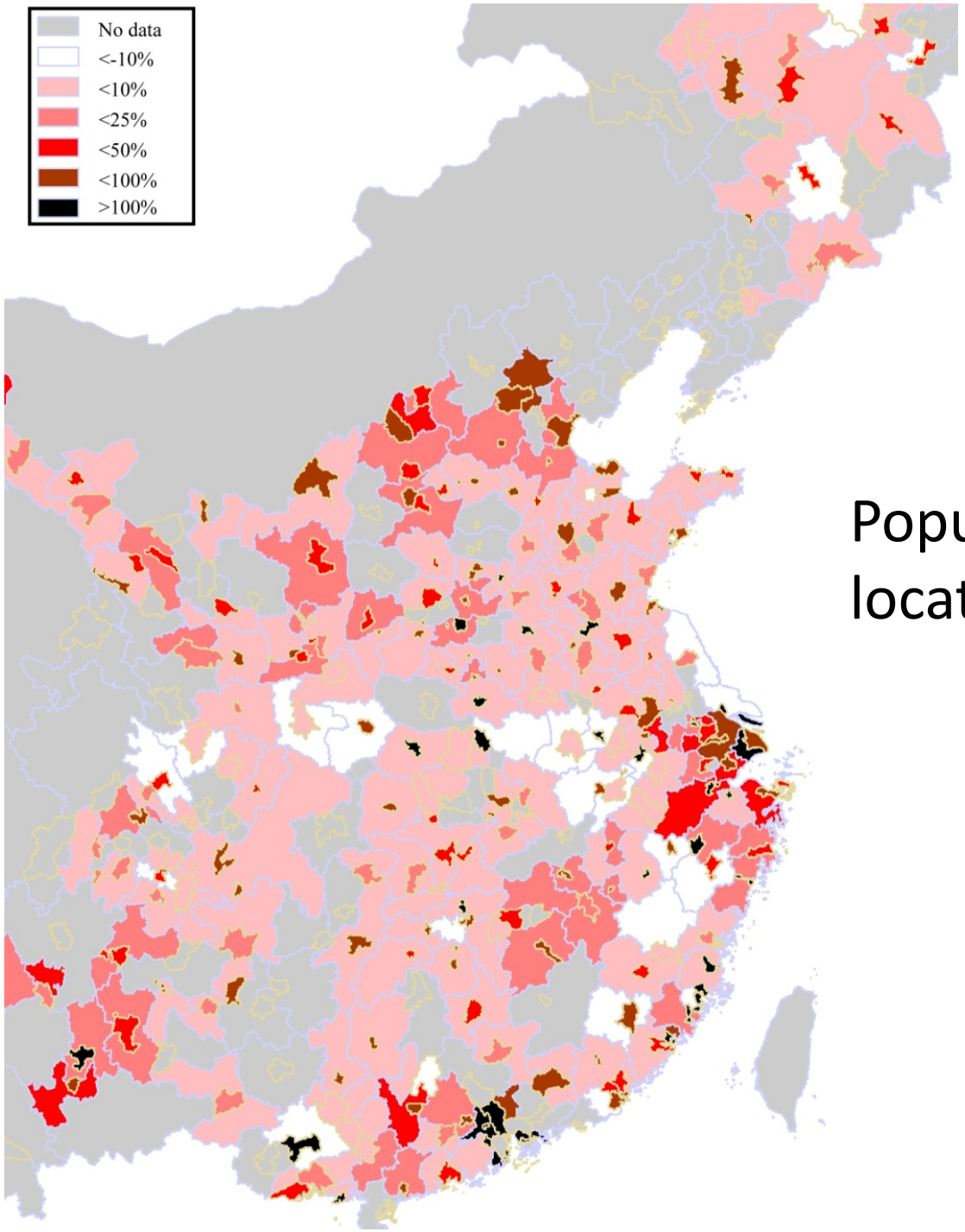
Lights at Night in 2009



Centralizing Population, Decentralizing Lights

Growth in Aggregate Lights & Population by Location, 1990-2010

	City Proper		Prefecture Remainder	
2010 Sample of 210 Prefectures				
	Lights	Population	Lights	Population
(Mean in 1990)		(982,333)		(2,995,989)
1990-2000	54%	27%	99%	4%
2000-2010	33%	22%	37%	1%
1990-2010	105%	55%	172%	5%
2000 Sample of 257 Prefectures				
	Lights	Population	Lights	Population
(Mean in 1990)		(955,683)		(2,953,557)
1990-2000	52%	25%	94%	4%
2000-2010	33%	NA	36%	NA
1990-2010	102%	NA	165%	NA



Population growth by location, 1990-2010

Decentralizing GDP in a Smaller Sample

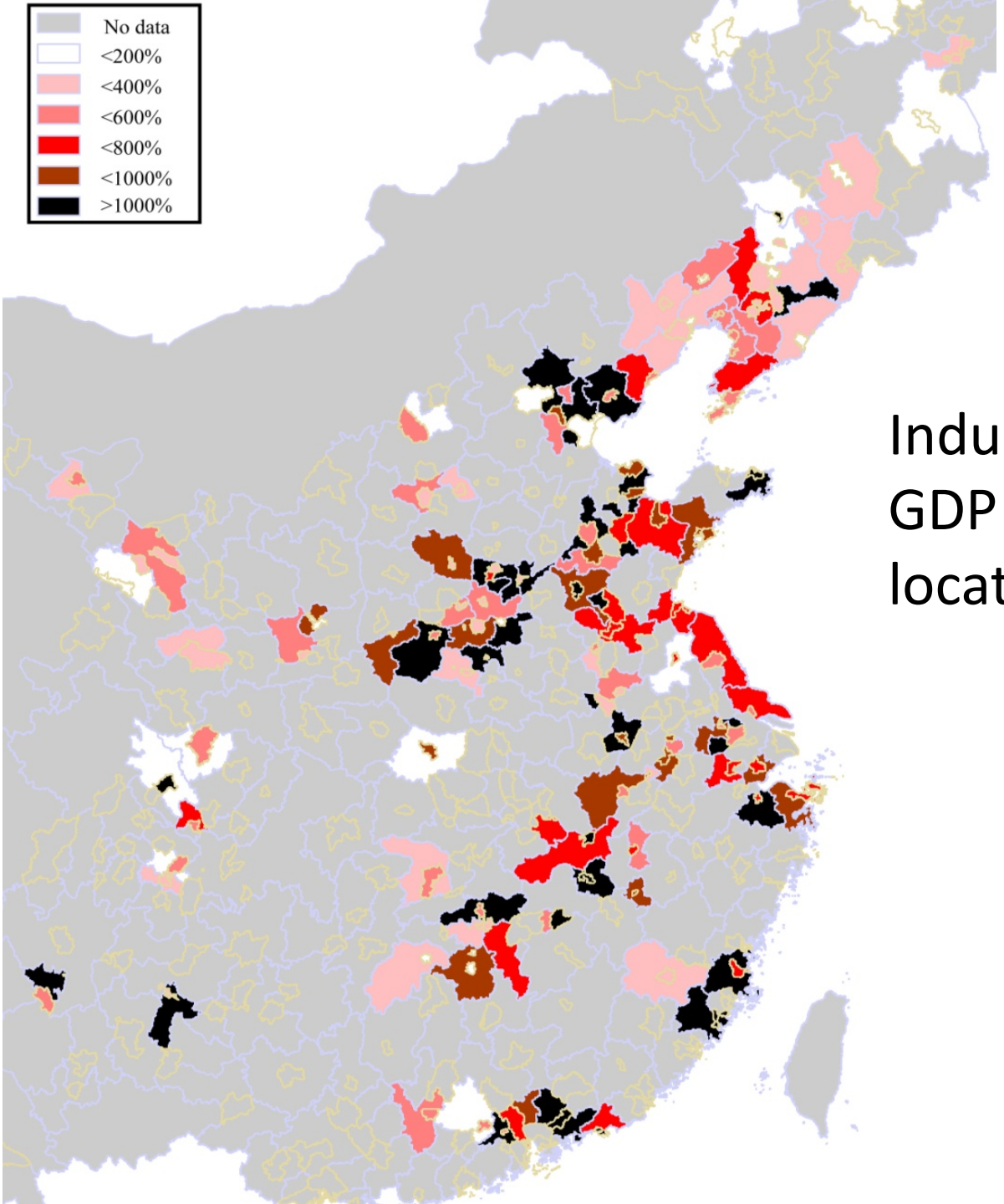
Growth in Aggregate GDP

Sample of 108 Prefectures With GDP Data

	City Proper		Prefecture Remainder	
	GDP	Industrial GDP	GDP	Industrial GDP
(Mean in 1990)	(20.5)	(12.3)	(17.5)	(7.0)
1990-2000	183%	138%	309%	366%
2000-2005	122%	117%	72%	92%
1990-2005	530%	417%	605%	794%

- Because we only observe GDP at the prefecture and city proper levels in 1990, we only report results here for prefectures that did not change geographies 1990-2005

- Much of the decentralization of GDP is driven by industry rather than services (or agriculture)



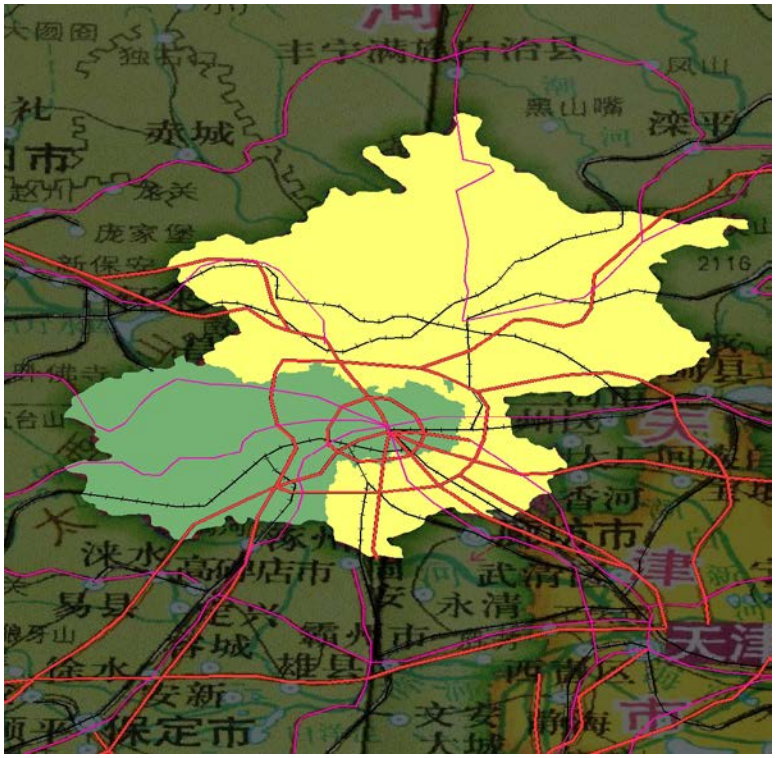
Industrial sector GDP growth by location, 1990-2005

Transport Infrastructure Data

- We digitized various classes of roads and rails from large scale national maps of China from 1962, 1990, 1999, 2005 and 2010.
  - Traced by hand
- Using the resulting digital networks, we construct the following measures of urban transport network capacity in each year
  - Radial roads or highways
  - Radial railroads
  - Total km of roads, highways or railroads in the central city and prefecture remainder
  - Ring road and rail capacity

Digitisation of Transport Infrastructure Information

Example: Beijing Prefecture in 2010



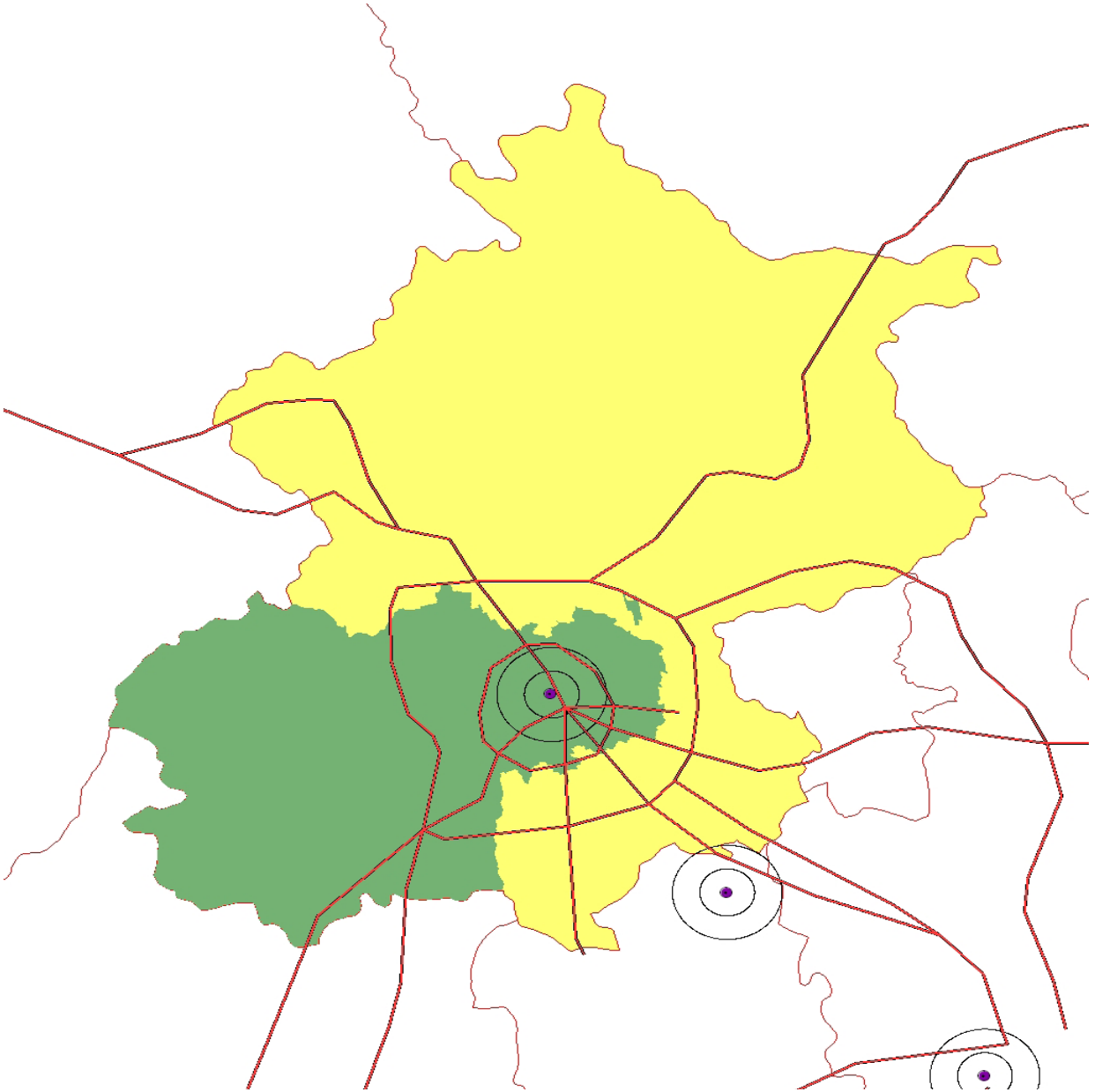
• Results are detailed enough for our purposes, measuring roads and rails within a few km of their actual locations

• In 1962 and 1999, we use all classes of roads reported on the map whereas in 2010 we use only express highways and national highways

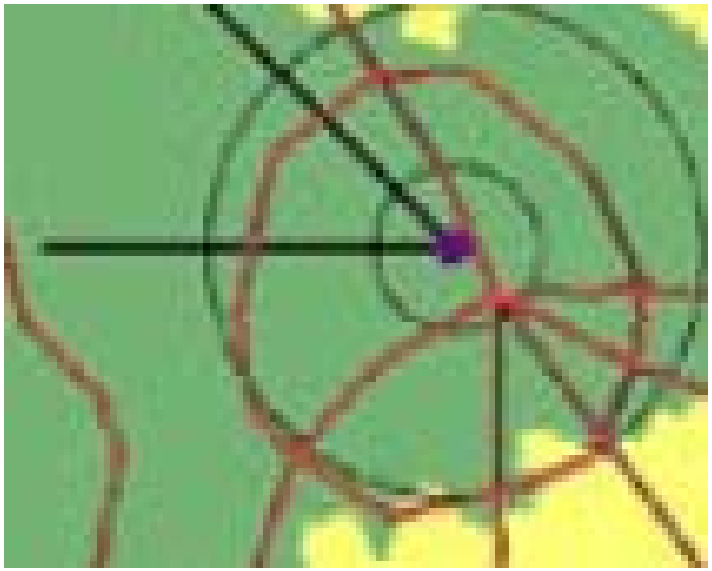
Measuring Radial Road/Rail Capacity

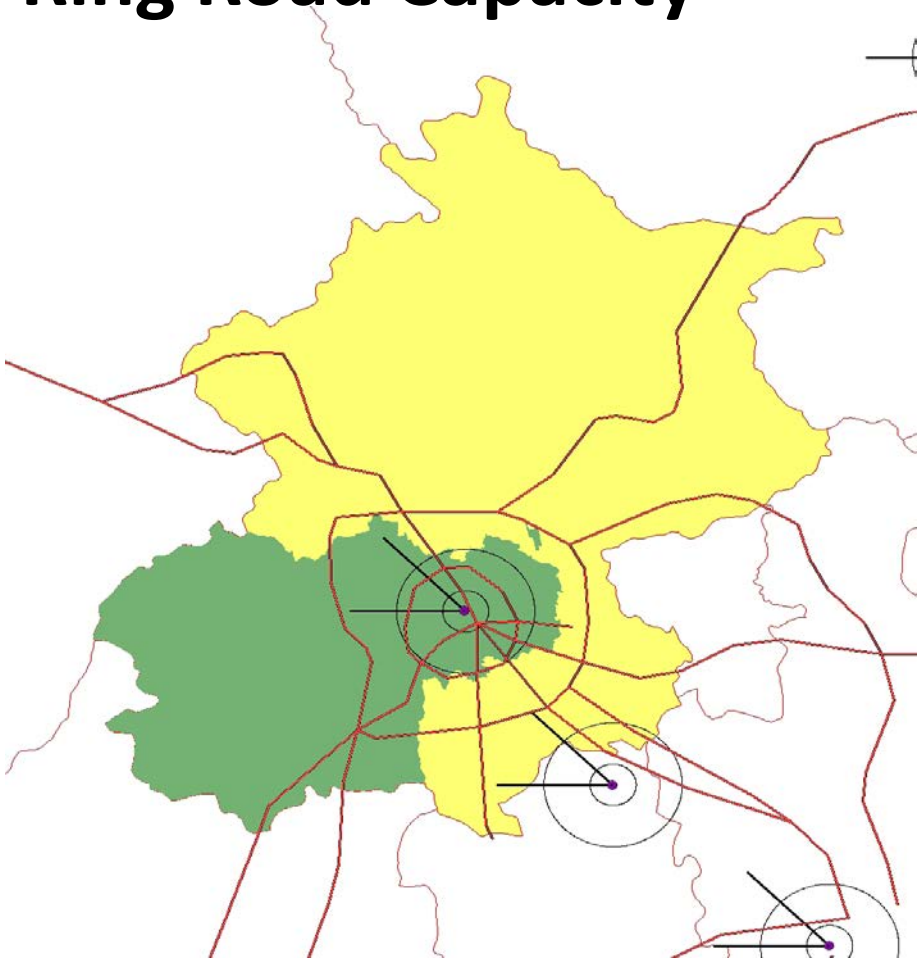
- Draw rings 5 and 10 km from the CBD.

The contribution to radial index is the minimum of the number of times the network crosses each ring [**6 (inner), not 8 (outer)**].



Measuring Ring Road Capacity



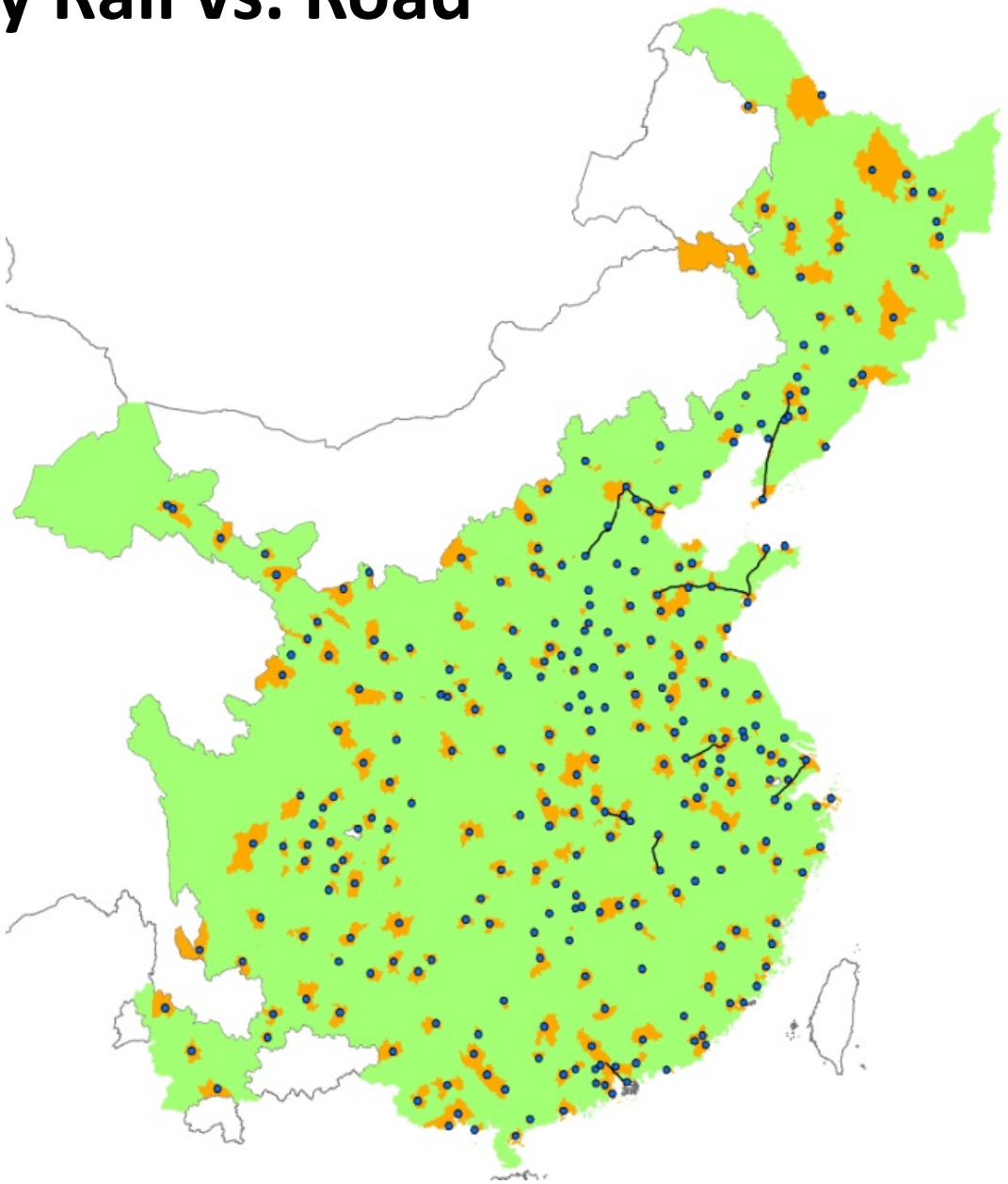


- Draw rings 5 and 9 km from the CBD. Draw rays heading west and northwest from the CBD (45^{o}). Index for this quadrant is the minimum of the number of times roads cross these rays.
- Repeat for each of the other 3 quadrants
- Repeat for 9-15km and 15-25 km distance bands [min. angle of ring road to ray is 54^{o} (vs. 90)].
- Sum the results for intersections **outside the central city**,
- **our index = 1 if this sum is positive, 0 otherwise**

Shipping by Rail vs. Road

Expressways in 1995

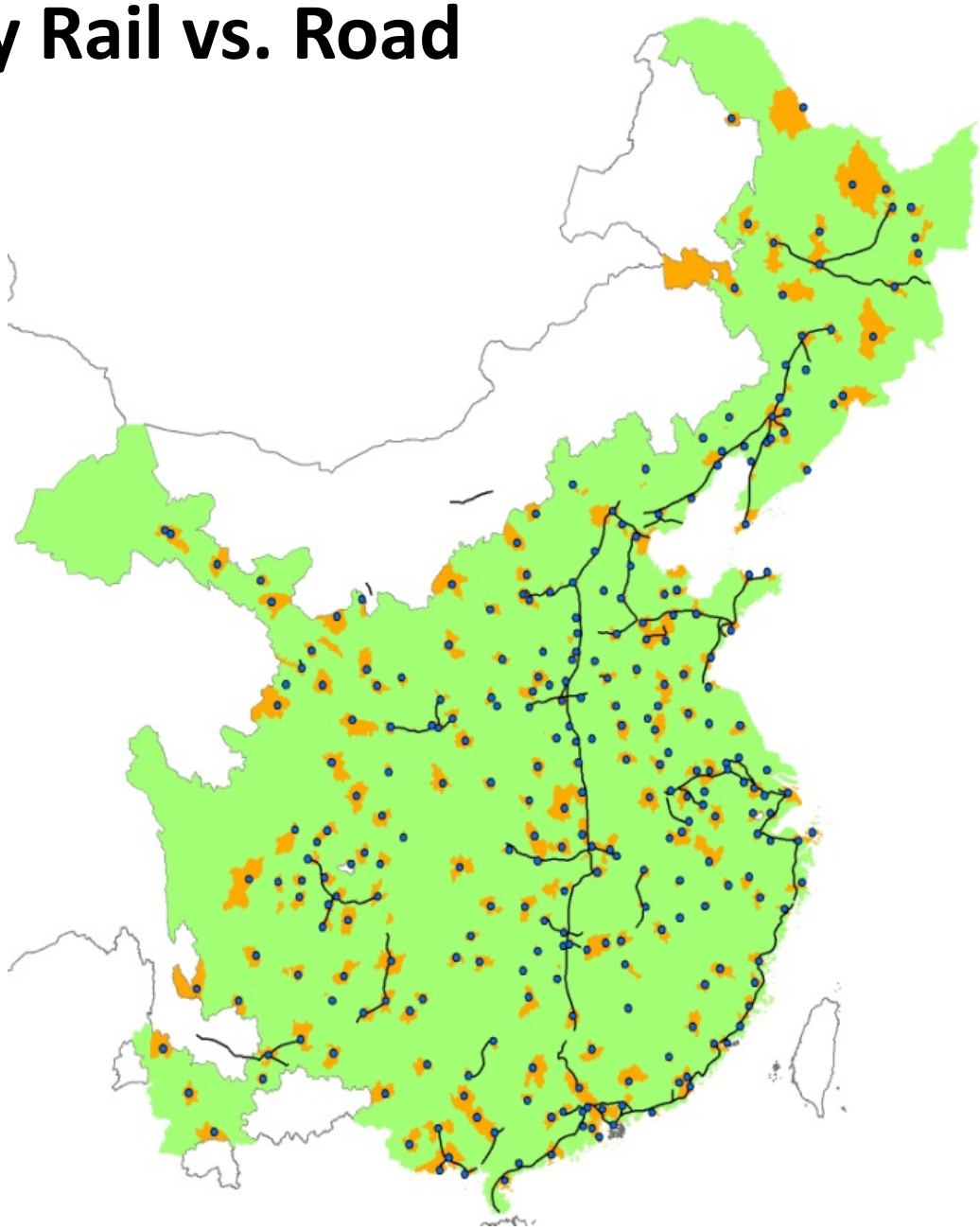
- Almost none



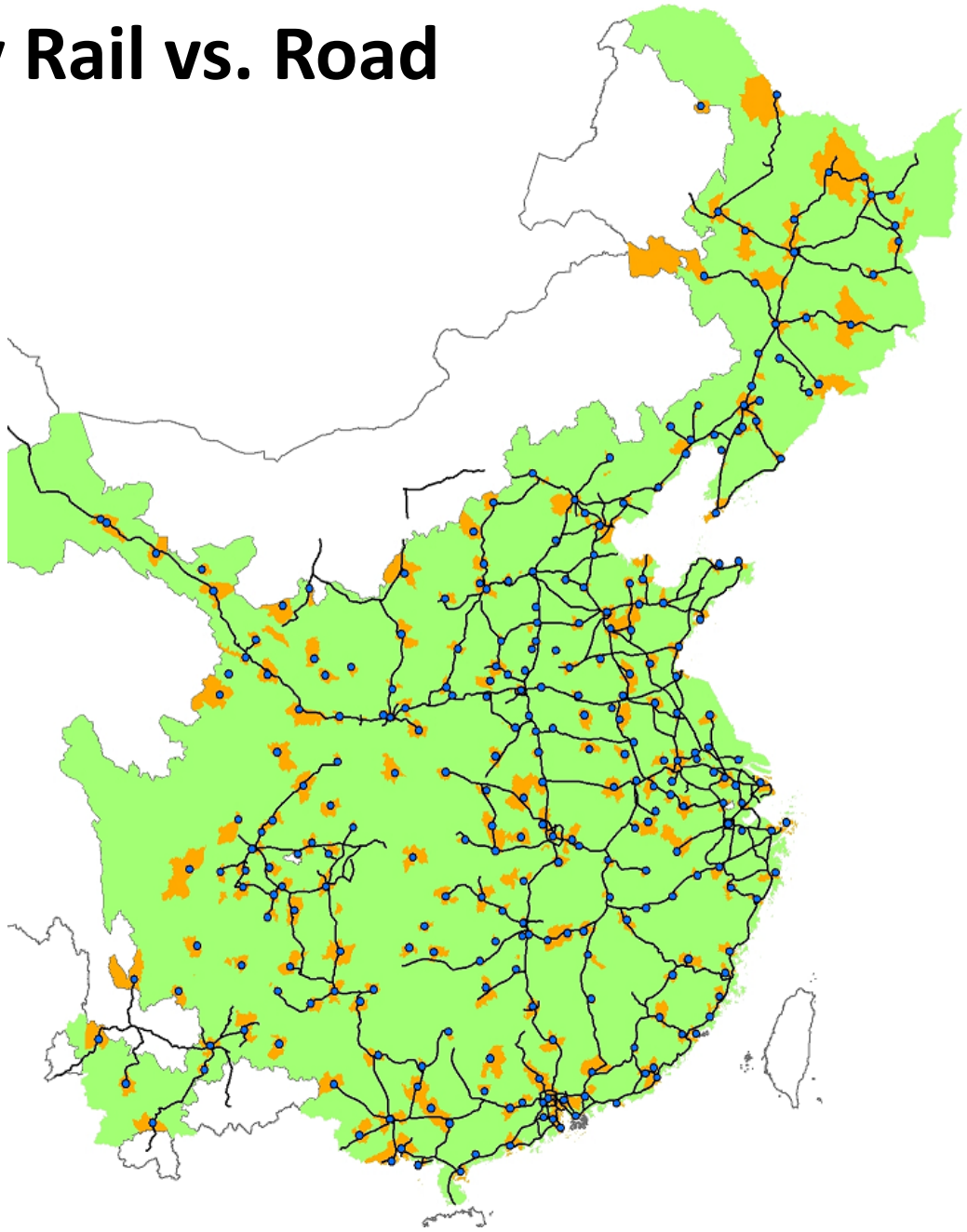
Shipping by Rail vs. Road

Expressways in 1999

- Sparse and not connected



Shipping by Rail vs. Road



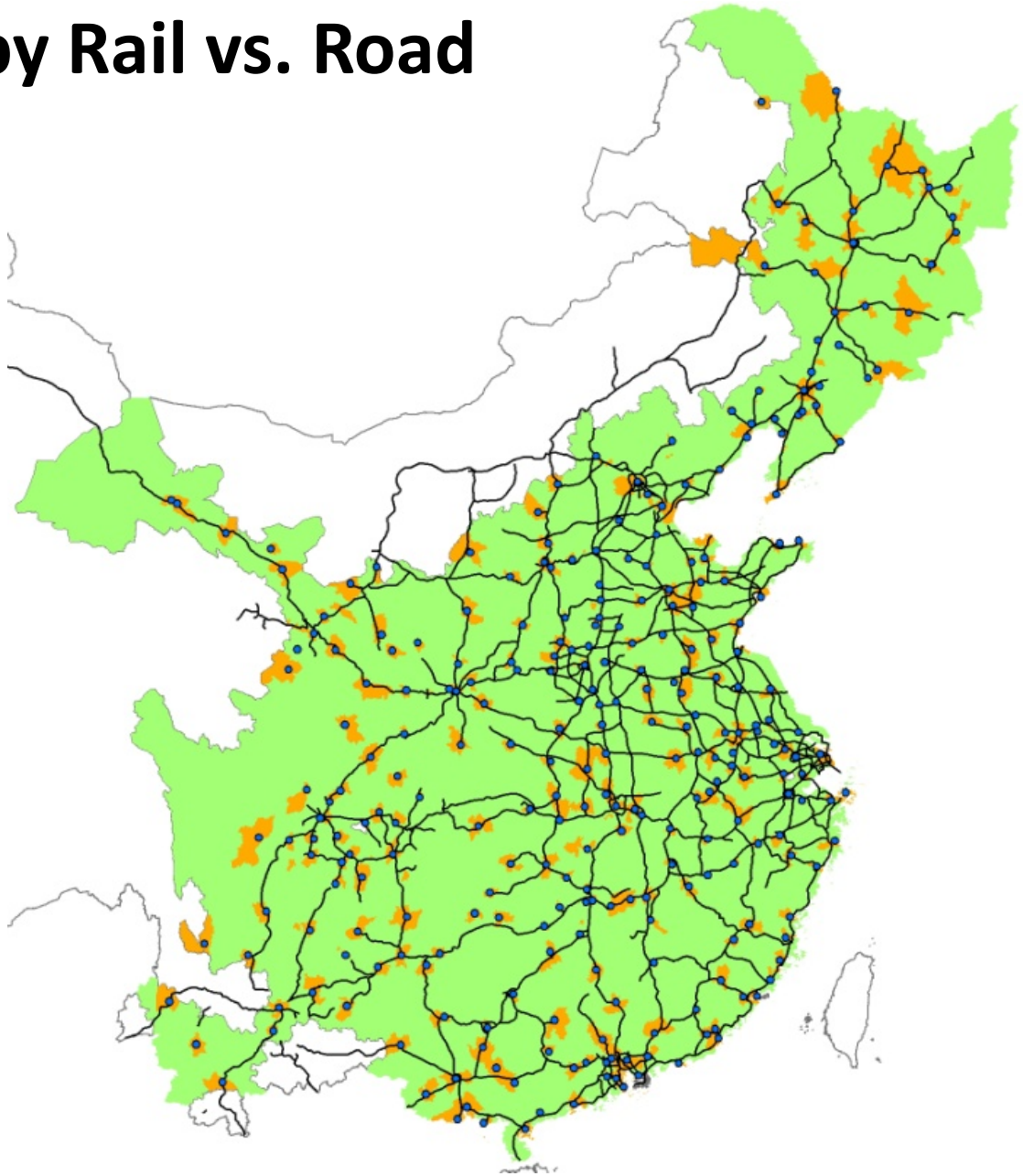
Expressways in 2005

- gap in center South and going North
- connect cities; no spurs

Shipping by Rail vs. Road

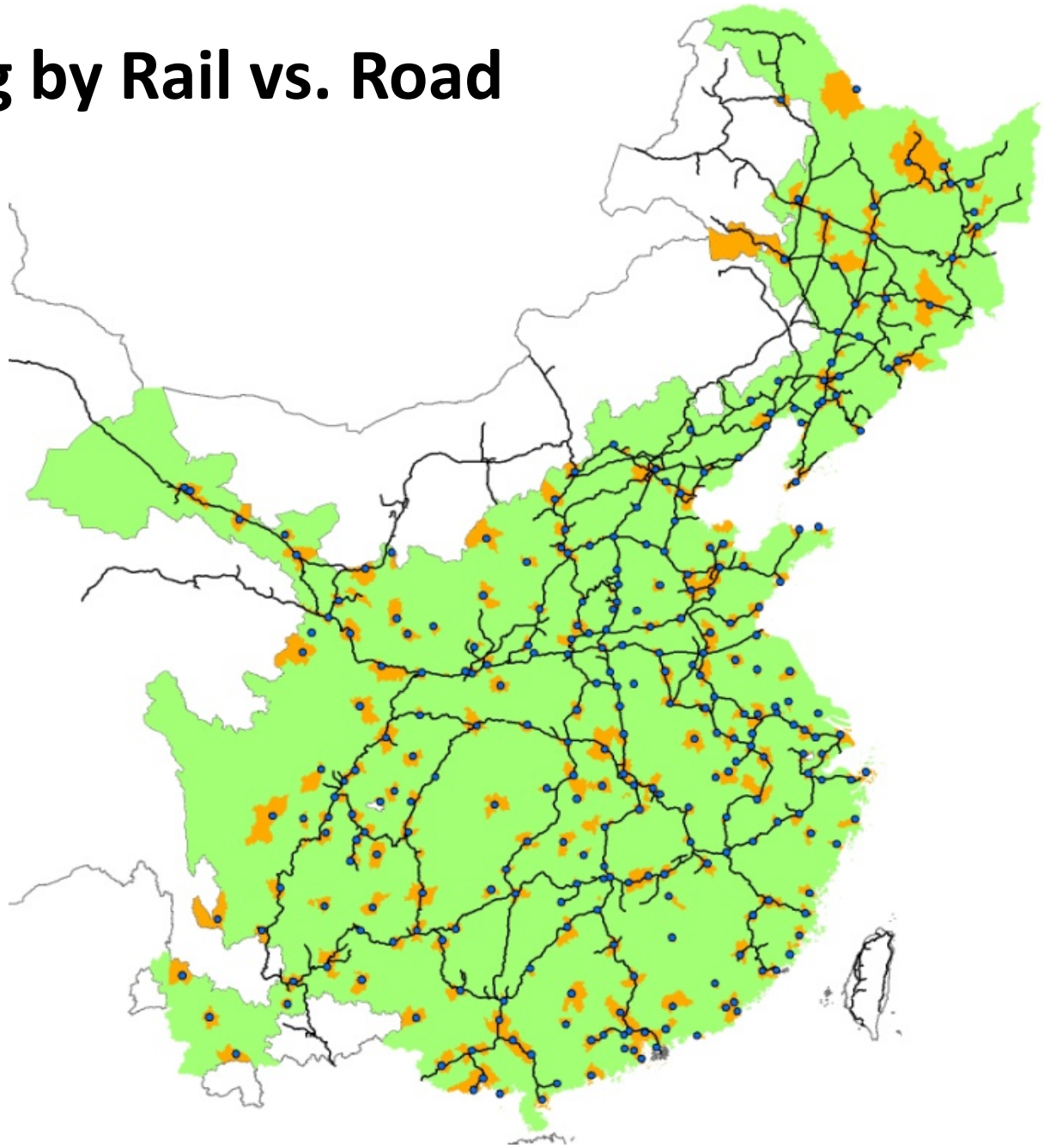
Expressways in 2010

- Most gaps filled in



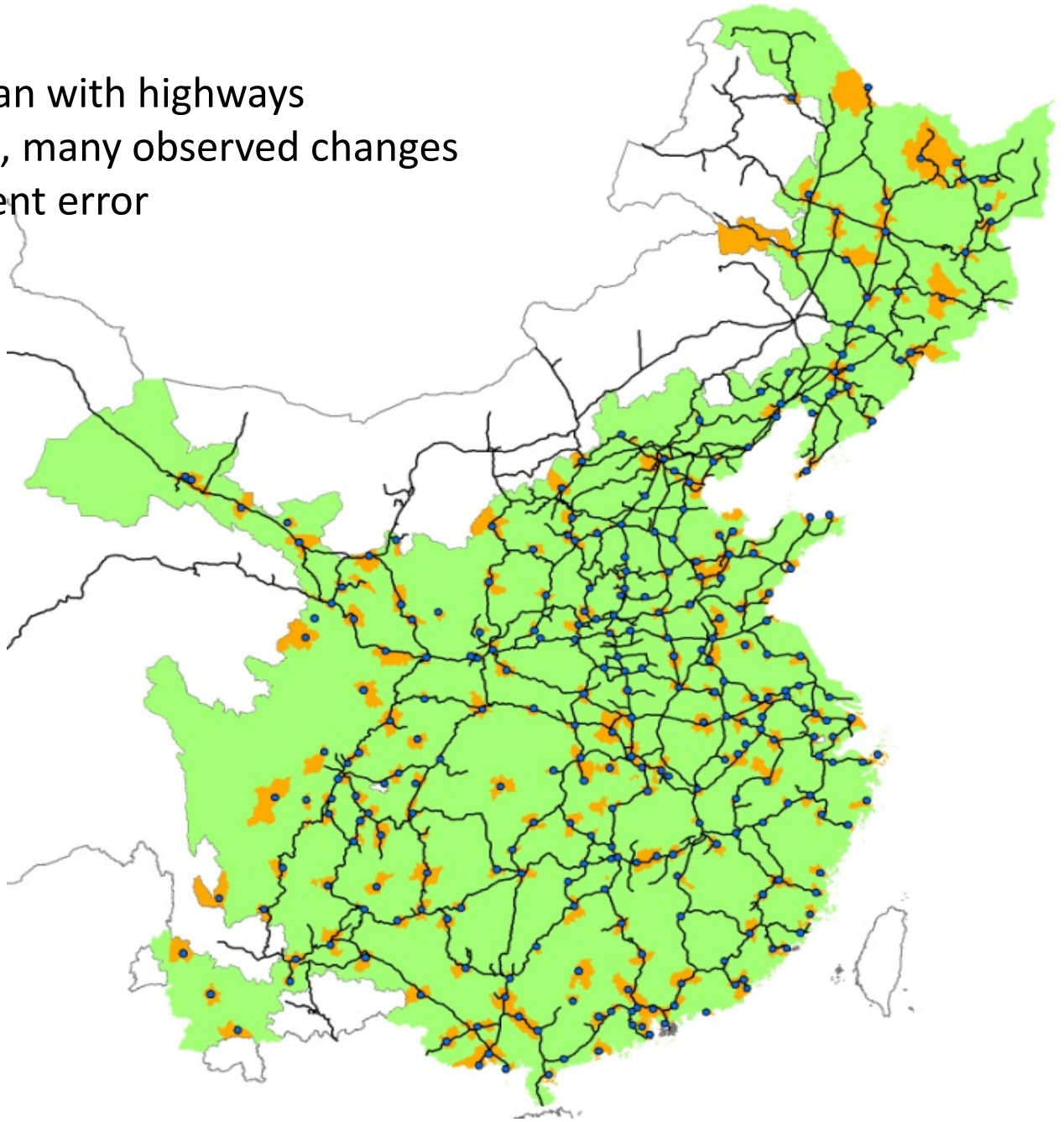
Shipping by Rail vs. Road

Railroads in 1990:
Country substantially covered



Rails in 2005

- Fewer changes than with highways
- At city level scales, many observed changes are just measurement error



Samples Used for Analysis

1. For 1990-2000 CC population growth: Full sample of **257** (of 286) Han Chinese prefectures
    - Start with a pop of more than 50,000 urban residents (lose 26)
    - Have suburban area (lose 3)
    - 88 promoted

2. For 1990-2010 CC population growth: Limited coverage in the 2010 census data available to us: use a sample of **210**

3. For 1990-2005 CC industrial GDP growth: CC sample of **205** for GDP and **187** for industrial sector GDP
    - Boundary changes with no rural GDP numbers
    - Because of limited GDP data availability, use lights at night data as an alternate measure of GDP

Empirical Strategy for Roads

For the effects of roads, we estimate regressions like in Baum-Snow, 2007:

- Conceptualize an Alonso-Muth-Mills equilibrium in year t>1990

$$\ln y_{tC} = A_0 + A_1 r_t + A_2 \ln y_{tP} + B_0 x_t + \delta + \varepsilon_t$$

- Conceptualize a planning equilibrium in year 1990 which has the same predictors plus additional predictors q, but different coefficients

$$\ln y_{1990C} = (A_0 + \Delta A_0) + (A_1 + \Delta A_1) r_{1990} + (A_2 + \Delta A_2) y_{1990P}$$
$$+ (B_0 + \Delta B_0) x_{1990} + C_0 q_{1990} + \delta + \varepsilon_{1990}$$

- Difference these two equations

$$\Delta_t \ln y_C = \Delta A_0 + A_1 \Delta_t r + \Delta A_1 r_{1990} + A_2 \Delta_t \ln y_P + \Delta A_2 \ln y_{1990P}$$
$$+ B_0 \Delta_t x + \Delta B_0 x_{1990} - C_0 q_{1990} + \Delta_t \varepsilon$$

- No highways in 1990. Assume $\Delta_t \mathbf{r} = \mathbf{r}_t$ (i.e., $\boldsymbol{r}_{1990} = 0$), resulting in

$$\Delta_t \ln y_C = \Delta A_0 + A_1 r_t + A_2 \Delta_t \ln y_P + \Delta A_2 \ln y_{1990P}$$
$$+ B_0 \Delta_t x + \Delta B_0 x_{1990} - C_0 q_{1990} + \Delta_t \varepsilon$$

Implementation

- Inclusion of prefecture level outcomes on the right hand side is essential for estimating causal effects on decentralization
    - Potential endogeneity concerns, which turn out to be very minor, will be addressed later

- Included in x (and justified by land use models) are
    - Central city area
    - Prefecture area
    - Various additional variables as robustness checks to account for income and housing supply elasticity differences across cities

- If we have valid instruments, we should need to control for nothing else beyond prefecture population to recover consistent causal effects on decentralization

    - Our instruments are only valid conditional on two variables:
        - 1990 agricultural hukou population measures the extent to which the prefecture is productive in agriculture. Since 1962 roads primarily moved agricultural goods to nearby urban centers, we need to control for this
        - Railroads primarily served provincial capitals, as they were manufacturing centers → control for provincial capital indicators

Empirical Strategy for Railroads

When evaluating the effects of railroads, we start with (from above)

$$\Delta_t \ln y_C = \Delta A_0 + A_1 \Delta_t r + \Delta A_1 r_{1990} + A_2 \Delta_t \ln y_P + \Delta A_2 \ln y_{1990P}$$
$$+ B_0 \Delta_t x + \Delta B_0 x_{1990} - C_0 q_{1990} + \Delta_t \varepsilon$$

measure of railroads: $\Delta A_1 + A_1 = 0;\ r_{1990} \approx r_{2005};\ \text{estimate } A_1$

$$\Delta_t \ln y_C = \Delta A_0 + A_1 r_t + A_2 \Delta_t \ln y_{tP} + \Delta A_2 \ln y_{1990P} + B_0 \Delta_t x + \Delta B_0 x_{1990} + \Delta_t \varepsilon$$

- Little rail construction after 1990 and can't confidently identify new and lost rails; No instruments for measured changes in rails.
- Fortunately, in 1990, most Chinese cities were still completely planned economies:
  - little commuting
  - Rural-urban legal separation: SOE's can't move out
- As a result, our estimates showing how market forces respond to the railroad network are comparable to those for highways

Main Identification Problem

- Highways built to serve growing cities. These cities would then look like they are centralizing because of the new roads when in fact the reverse is true.
- Cities with more railroads have more industry – more pressure for industrial decentralization as the economy matures
- As a solution, we instrument for 1999, 2005 or 2010 highways and rails with corresponding 1962 measures (Z)

Using the 1962 Road Network for Instruments

- Strong instruments: New highways follow old paths. Cost issue: Right of way and access points (city gates) already in place.
- Valid strategy if conditional on control variables, there are no unobservables correlated with the 1962 network that drive decentralization
    - vs. 1982, 1924
- 1962 road network was of very poor quality
    - 2 lane maximum; not all paved
    - primarily used for local shipping of agricultural goods from rural hinterlands to nearby prefectural cities (not commuting)
        - Empirically, 1962 roads are predicted by 1990 agricultural population outside of the city proper
            - Might affect decentralization directly
            - Important control variable in all regressions

Using the 1962 Rail Network for Instruments

- 1962 rail network
  - Private and foreign ventures, Japanese, civil war, Russians
  - Post 62, third front into Sichuan region
- Used primarily for
  - Long-distance shipping of raw materials and fuels
  - Trade of industrial products (short or long haul)
  - Not related to access to suburban sidings
- There were more 1962 railroads in provincial capitals.
  - Nodal shipping points
  - Control for this indicator in all regressions

First Stage: Highways

	2010 Hwy Rays (1)	1999 Hwy Rays (2)
highway rays in 1962	0.37***	0.32***
	(0.080)	(0.079)
railroad rays in 1962	0.24*	0.17**
	(0.13)	(0.078)
highway rings in 1962	0.55	-0.56
	(1.04)	(0.37)
ln(central city area)	0.039	0.16
	(0.16)	(0.11)
ln(prefecture area)	0.25	0.23
	(0.20)	(0.14)
ln(1990 agric. *hukou* pop	0.0098	0.36**
outside central city)	(0.14)	(0.14)
ln(1992 prefecture lights)	0.44***	-0.042
	(0.15)	(0.13)
Δ ln(prefecture population)	-0.18	
1990-2010	(0.60)	
Δ ln(prefecture population)		1.76***
1990-2000		(0.48)
Δ ln(prefecture lights)	-0.15	0.020
1992-20xx	(0.53)	(0.32)
provincial capital indicator	1.91***	1.44***
	(0.42)	(0.46)
constant	-5.06*	-6.30***
	(2.49)	(2.14)
Observations	210	257
R-squared	0.31	0.29

First Stage: Rails and Ring Roads

	2005 Rail Rays (3)	1999 Hwy Rings (4)
highway rays in 1962	0.022	-0.0043
	(0.082)	(0.018)
railroad rays in 1962	0.50***	0.0045
	(0.057)	(0.023)
highway rings in 1962	0.013	0.44***
	(0.26)	(0.12)
ln(central city area)	0.069	-0.073***
	(0.12)	(0.023)
ln(prefecture area)	-0.13	-0.030
	(0.16)	(0.043)
ln(1990 agric. *hukou* pop	0.19	0.0059
outside central city)	(0.12)	(0.020)
ln(1992 prefecture lights)	0.030	-0.0087
	(0.17)	(0.032)
Δ ln(prefecture population)		
1990-2010		
Δ ln(prefecture population)	-1.55***	0.15
1990-2000	(0.41)	(0.13)
Δ ln(prefecture lights)	-0.46	0.044
1992-20xx	(0.36)	(0.061)
provincial capital indicator	0.096	0.13
	(0.24)	(0.096)
constant	-0.62	0.86*
	(1.79)	(0.49)
Observations	205	257
R-squared	0.29	0.16

OLS Relationships Between Highway Rays and Central City Populations

	Δ ln(CC Pop), 1990-2010		Δ ln(CC Pop), 1990-2000	
	(1)	(2)	(3)	(4)
highway rays in 2010	0.014	-0.011		
	(0.011)	(0.0073)		
highway rays in 1999			0.022***	0.011
			(0.0076)	(0.0073)
ln(central city area)		-0.12***		-0.063***
		(0.021)		(0.016)
ln(prefecture area)		0.031		0.016
		(0.030)		(0.014)
ln(1990 agric. *hukou* pop		0.070**		0.035*
outside central city)		(0.029)		(0.018)
ln(1992 prefecture lights)		0.021		0.016
		(0.026)		(0.012)
Δ ln(prefecture population)		0.79***		0.80***
1990-20xx[a]		(0.11)		(0.085)
Δ ln(prefecture lights)		0.090*		0.072**
1992-20xx		(0.046)		(0.034)
provincial capital indicator		0.087		0.0017
		(0.059)		(0.032)
constant	0.36***	-0.43	0.17***	-0.28
	(0.058)	(0.38)	(0.031)	(0.24)
Observations	210	210	257	257
R-squared	0.01	0.56	0.03	0.39

IV Estimates of Effects of Highway Rays on Central City Population

	Δ ln(CC Pop), 1990-2010		
	(1)	(2)	(3)
highway rays in 2010	-0.030	-0.046**	-0.038*
	(0.030)	(0.022)	(0.022)
ln(central city area)		-0.12***	-0.13***
		(0.020)	(0.020)
ln(prefecture area)		0.043	0.058*
		(0.027)	(0.034)
ln(1990 agric. *hukou* pop		0.076***	0.064*
outside central city)		(0.028)	(0.035)
ln(1992 prefecture lights)		0.036	0.037
		(0.027)	(0.030)
Δ ln(prefecture population)		0.79***	0.75***
1990-20xx[a]		(0.088)	(0.092)
Δ ln(prefecture lights)		0.083*	0.076
1992-20xx		(0.045)	(0.053)
provincial capital indicator		0.16**	0.16**
		(0.081)	(0.076)
ln(precipitation)			0.029
			(0.039)
central city elevation range			8.1e-06
			(0.000023)
prefecture elevation range			1.3e-07
			(0.000011)
ln(distance to coast)			-0.0086
			(0.014)
constant	0.49***	-0.66*	-0.77**
	(0.11)	(0.35)	(0.37)
Observations	210	210	210
First stage F	30.3	23.2	26.3

IV Estimates of Effects of Highway Rays on Central City Population

	Δ ln(CC Pop), 1990-2000		
	(4)	(5)	(6)
highway rays in 1999	-0.0053	-0.047***	-0.042***
	(0.015)	(0.014)	(0.013)
ln(central city area)		-0.054***	-0.052***
		(0.016)	(0.016)
ln(prefecture area)		0.032***	0.055***
		(0.011)	(0.012)
ln(1990 agric. *hukou* pop		0.065***	0.053***
outside central city)		(0.020)	(0.018)
ln(1992 prefecture lights)		0.013	0.0053
		(0.016)	(0.019)
Δ ln(prefecture population)		0.91***	0.91***
1990-20xx[a]		(0.095)	(0.098)
Δ ln(prefecture lights)		0.073*	0.050
1992-20xx		(0.038)	(0.039)
provincial capital indicator		0.097**	0.097**
		(0.042)	(0.039)
ln(precipitation)			0.029**
			(0.014)
central city elevation range			-0.000038**
			(0.000016)
prefecture elevation range			8.9e-06
			(8.7e-06)
ln(distance to coast)			-0.0084
			(0.0057)
constant	0.25***	-0.76**	-0.87***
	(0.055)	(0.30)	(0.31)
Observations	257	257	257
First stage F	23.8	17.0	15.2

Comments

- Radial highways retard centralization
- Consistent with differencing long-run Alonso-Muth-Mills equilibria. Coefficients for 90-00 and 90-10 the same.
  - But highway definition changes
- Robust to samples
  - Drop big or small
  - Drop CBD-gap cities: stronger
  - Drop cities where CC expanded
    - Coefficients drop 25%

Effects of Other forms of Infrastructure

- Highway kms
- Rails
- Ring Roads (examined later)

Estimated IV Effects of Other Types of Infrastructure

	Δ ln(CC Pop), 1990-2010		
	(1)	(2)	(3)
highway rays in 2010 or 1999	-0.054**	-0.052**	-0.052**
	(0.025)	(0.023)	(0.024)
ln(km of highways in prefecture)	0.045		
in 2010 or 1999	(0.17)		
ln(km of highways in prefecture		0.027	
outside of CC) in 2010 or 1999		(0.071)	
railroad rays in 2010 or 1999			0.039
			(0.048)
ln(central city area)	-0.12***	-0.11***	-0.12***
	(0.019)	(0.025)	(0.024)
ln(prefecture area)	0.021	0.020	0.045
	(0.11)	(0.074)	(0.028)
ln(1990 agric. *hukou* pop	0.071	0.076**	0.071***
outside central city)	(0.047)	(0.035)	(0.024)
ln(1992 prefecture lights)	0.022	0.025	0.030
	(0.031)	(0.023)	(0.025)
Δ ln(prefecture population)	0.79***	0.79***	0.82***
1990-20xx[a]	(0.093)	(0.095)	(0.087)
Δ ln(prefecture lights)	0.077*	0.077*	0.100*
1992-20xx	(0.044)	(0.045)	(0.058)
provincial capital indicator	0.17**	0.17**	0.15*
	(0.083)	(0.079)	(0.079)
constant	-0.51	-0.55	-0.64**
	(0.79)	(0.57)	(0.31)
Observations	209	205	210
First stage F	6.15	11.0	8.19

Estimated IV Effects of Other Types of Infrastructure

	Δ ln(CC Pop), 1990-2000		
	(4)	(5)	(6)
highway rays in 2010 or 1999	-0.047***	-0.047***	-0.047***
	(0.015)	(0.017)	(0.018)
ln(km of highways in prefecture)	-0.0034		
in 2010 or 199	(0.085)		
ln(km of highways in prefecture		0.040	
outside of CC) in 2010 or 199		(0.067)	
railroad rays in 2010 or 1999			0.0013
			(0.024)
ln(central city area)	-0.054***	-0.046**	-0.054***
	(0.016)	(0.019)	(0.016)
ln(prefecture area)	0.034	-0.0075	0.032***
	(0.065)	(0.069)	(0.011)
ln(1990 agric. *hukou* pop	0.065***	0.062***	0.065***
outside central city)	(0.021)	(0.022)	(0.020)
ln(1992 prefecture lights)	0.014	0.0094	0.013
	(0.018)	(0.017)	(0.018)
Δ ln(prefecture population)	0.91***	0.86***	0.92***
1990-20xx[a]	(0.10)	(0.11)	(0.100)
Δ ln(prefecture lights)	0.075*	0.065	0.074
1992-20xx	(0.041)	(0.040)	(0.048)
provincial capital indicator	0.098**	0.098**	0.096**
	(0.043)	(0.045)	(0.041)
constant	-0.76*	-0.59	-0.75**
	(0.42)	(0.50)	(0.30)
Observations	255	253	257
First stage F	6.99	8.07	6.51

Effects on Production Decentralization

- Industrial GDP vs. Total GDP vs. lights at night
  - Industrial GDP is best measured in 1990 and has the most consistent definition over time
  - Coverage limitations in GDP data mean we also use lights at night
- Highways vs. Railroads
  - Radial, ring and network length

	Δln(Ind Sect GDP)		
	(1)	(2)	(3)
highway rays in 2005	-0.028		
	(0.083)		
railroad rays in 2005		-0.26**	
		(0.11)	
ln(2005 km of railroads in prefecture)			-0.82***
			(0.24)
ln(central city area)	0.12*	0.11*	0.11
	(0.066)	(0.068)	(0.065)
ln(prefecture area)	-0.29**	-0.31***	0.22
	(0.13)	(0.11)	(0.17)
ln(1990 agric. *hukou* pop outside central city)	0.28***	0.31***	0.29***
	(0.11)	(0.11)	(0.11)
ln(1992 prefecture lights)	-0.010	0.054	0.15
	(0.13)	(0.11)	(0.14)
Δ ln(prefecture population) 1990-20xx[a]	1.67**	1.37**	0.80
	(0.82)	(0.69)	(0.64)
Δ ln(prefecture lights) 1992-20xx	0.31	0.14	0.046
	(0.22)	(0.28)	(0.24)
provincial capital indicator	-0.40**	-0.31	-0.22
	(0.19)	(0.21)	(0.19)
constant	-0.63	-0.86	-2.56
	(1.67)	(1.64)	(2.09)
Observations	187	187	184
First stage F	16.7	48.3	16.4

OLS rays coefficient for industrial GDP is -.06

	ΔIn(GDP)			ΔIn(Lights)		
	(4)	(5)	(6)	(7)	(8)	(9)
highway rays in 2005	0.0049			0.015		
	(0.048)			(0.029)		
railroad rays in 2005		-0.17***			-0.044*	
		(0.064)			(0.026)	
ln(2005 km of railroads in prefecture)			-0.54***			-0.22*
			(0.15)			(0.12)
ln(central city area)	0.015	0.015	-0.0011	0.071***	0.076***	0.072***
	(0.047)	(0.048)	(0.047)	(0.024)	(0.023)	(0.023)
ln(prefecture area)	-0.20**	-0.20***	0.17	-0.090*	-0.087**	0.040
	(0.077)	(0.070)	(0.11)	(0.048)	(0.042)	(0.088)
ln(1990 agric. *hukou* pop outside central city)	0.13**	0.17***	0.16***	-0.00041	0.024	0.030
	(0.056)	(0.063)	(0.063)	(0.042)	(0.036)	(0.038)
ln(1992 prefecture lights)	0.072	0.090	0.15*	0.020	0.020	0.063
	(0.076)	(0.063)	(0.082)	(0.040)	(0.032)	(0.041)
Δ ln(prefecture population) 1990-20xx[a]	0.51**	0.31	-0.0054	-0.053	-0.088	-0.33*
	(0.24)	(0.20)	(0.23)	(0.17)	(0.14)	(0.17)
Δ ln(prefecture lights) 1992-20xx	0.30**	0.17	0.081	0.93***	0.89***	0.81***
	(0.15)	(0.17)	(0.16)	(0.080)	(0.079)	(0.085)
provincial capital indicator	-0.057	0.036	0.12	-0.11*	-0.066	-0.033
	(0.097)	(0.13)	(0.13)	(0.065)	(0.051)	(0.052)
constant	0.68	0.37	-0.75	0.076	-0.19	-0.76
	(0.95)	(1.06)	(1.26)	(0.38)	(0.30)	(0.49)
Observations	205	205	202	257	257	248
First stage F	16.9	76.4	25.8	35.8	90.1	20.9

Highways vs. Rail Results

- How may highway rays lead to population decentralization?
  - Some high income suburbanize (we think)
  - Local hukou people from rural sector can commute (full or part time), leading to less migration pressure
- Why do highway rays not affect production decentralization?
  - Highways for long distance transport only accelerates in last 7-8 years
- If rails lead to production decentralization, why not lead (indirectly) to population decentralization?
  - Not absolute job loss in city: compositional change
    - Huge growth of business & financial service sector overall , focused on CC
  - Separation of where work and live: commuting now common
  - Increasingly employ those who would never have lived in center
    - Inter-provincial migrant workers (not so much locals) in the factories in dorms or rural housing: never would go to CC to begin with.

Ring Roads

- Uncommon
- Just an indicator: any ring road or not
  - Attempts to use more subtle ring road measures have weak first stages
- IV issues
  - Because they are uncommon, we are estimating something closer to LATE & TT than ATE
  - 1962 ring capacity does exist throughout the population distribution of cities

	ΔLn(CC Pop)	
	1990-2010	1990-2000
	(1)	(2)
highway rays at time t	-0.038	-0.054***
	(0.024)	(0.019)
railroad rays at time t		
highway ring outside CC	0.055	-0.20**
indicator at time t	(0.099)	(0.086)
ln(central city area)	-0.11***	-0.072***
	(0.024)	(0.018)
ln(prefecture area)	0.038	0.030**
	(0.025)	(0.013)
ln(1990 agric. *hukou* pop	0.073***	0.067***
outside central city)	(0.026)	(0.024)
ln(1992 prefecture lights)	0.034	0.011
	(0.026)	(0.016)
Δ ln(prefecture population)	0.79***	0.95***
1990-20xx[a]	(0.087)	(0.11)
Δ ln(prefecture lights)	0.092**	0.079**
1992-20xx	(0.039)	(0.038)
provincial capital indicator	0.14	0.13**
	(0.088)	(0.053)
constant	-0.65*	-0.58*
	(0.36)	(0.35)
Observations	210	257
First stage F	4.66	8.61

Cities with ring roads . 1962: 5.5% (3.3%); 1999: 14%; 2010 20%.

	ΔIn(CC Ind. GDP) 1990-2005		ΔIn(CC GDP) 1990-2005	
	(3)	(4)	(5)	(6)
highway rays at time t	-0.089		-0.073	
	(0.12)		(0.10)	
railroad rays at time t		-0.28**		-0.18***
		(0.11)		(0.071)
highway ring outside CC	-0.76*	-0.80***	-0.54*	-0.46**
indicator at time t	(0.42)	(0.28)	(0.31)	(0.22)
ln(central city area)	0.029	-0.00036	-0.041	-0.050
	(0.075)	(0.067)	(0.046)	(0.043)
ln(prefecture area)	-0.27**	-0.32***	-0.19**	-0.21***
	(0.14)	(0.10)	(0.084)	(0.064)
ln(1990 agric. *hukou* pop	0.36***	0.35***	0.21**	0.19***
outside central city)	(0.10)	(0.089)	(0.098)	(0.064)
ln(1992 prefecture lights)	-0.036	0.059	0.047	0.097*
	(0.11)	(0.093)	(0.072)	(0.054)
Δ ln(prefecture population)	2.26***	1.77***	0.69*	0.28
1990-20xx[a]	(0.86)	(0.66)	(0.36)	(0.21)
Δ ln(prefecture lights)	0.25	0.094	0.25	0.15
1992-20xx	(0.23)	(0.30)	(0.16)	(0.18)
provincial capital indicator	-0.38*	-0.34	0.046	0.057
	(0.22)	(0.25)	(0.14)	(0.14)
constant	-0.72	-0.40	0.46	0.73
	(1.68)	(1.54)	(1.21)	(0.95)
Observations	187	187	205	205

Cities with ring roads . 1962: 5.5% (3.3%); 1999: 14%; 2010 20%.

Ring Roads Summary

- Influence both population and GDP decentralization
- Effects are in addition to existing documented effects of radial highways and railroads

Public Transit & Waterways

- Estimating effects of public buses & trolleys
  - Data only available for 2005 definition core cities
  - Instrumenting with 1990 prefecture transport service employees yields similar coefficients, larger standard errors
- Estimating effects of navigable waterways
  - We do not have an IV strategy here

Effects of Public Transport and Waterways

	∆ln(CC Pop) 1990-2010 (1)	∆ln(CC Ind. GDP) 1990-2005 (3)	∆ln(CC GDP) 1990-2005 (4)
highway rays in 2010	-0.039*		
	(0.022)		
ln(central city buses & trolleys in 2005)	0.028*		
	(0.016)		
railroad rays in 2005		-0.26**	-0.16**
		(0.11)	(0.066)
river & canal rays		0.011	0.020
		(0.023)	(0.015)
ln(central city area)	-0.12***	0.11*	0.017
	(0.019)	(0.068)	(0.047)
ln(prefecture area)	0.046	-0.31***	-0.20***
	(0.028)	(0.11)	(0.071)
ln(1990 agric. *hukou* pop outside central city)	0.067**	0.30***	0.16**
	(0.029)	(0.11)	(0.068)
ln(1992 prefecture lights)	0.021	0.057	0.096
	(0.031)	(0.11)	(0.064)
∆ ln(prefecture population) 1990-20xx[a]	0.76***	1.37**	0.33*
	(0.090)	(0.69)	(0.19)
∆ ln(prefecture lights) 1992-20xx	0.095**	0.14	0.17
	(0.041)	(0.28)	(0.17)
provincial capital indicator	0.10	-0.33	0.00033
	(0.083)	(0.21)	(0.12)
constant	-0.61	-0.85	0.39
	(0.38)	(1.64)	(1.04)
N	208	187	205
First stage F	28.0	44.2	67.0

Handling Potentially Endogenous Prefecture Population Growth

- All estimates in regressions excluding prefecture population growth and lights growth yield transport coefficients that are statistically indistinguishable from those reported above
  - These reflect both the effects on decentralization and city growth and we might thus expect them to be positively biased
- If unobservables predict central city population or we measure central city population with error, one can show a downward bias in the transport coefficients if transport and prefecture population growth are positively correlated
- Estimates with and without controls for prefecture population growth thus provide bounds which in our case are very tight on the true causal effects of transport
- Alternatively, one can instrument for prefecture population growth
  - Competition effect of nearby urban population (strong first stage)
  - Stock effect of nearby rural population (weak first stage)
  - Bartik (industry shift-share) instruments are weak

Results When Instrumenting for Transport and Prefecture Population Growth

	∆ln(CC Pop) 1990-2010 (1)	∆ln(CC Pop) 1990-2000 (2)	∆ln(CC Ind GDP) 1990-2005 (3)	∆ln(CC GDP) 1990-2005 (4)
highway rays in 2010 or 1999	-0.033	-0.042***		
	(0.034)	(0.015)		
railroad rays in 2005			-0.25***	-0.14**
			(0.094)	(0.057)
N	210	257	187	205
First stage F	2.49	8.63	8.01	2.65

- Regressions exclude prefecture lights levels and growth
  - Difficult to instrument for these elements

Placebo Results 1982-1990

	∆ln(CC Pop) 1982-1990 (1)	∆ln(CC Pop) 1982-1990] (2)
highway rays in 2010	-0.017	
	(0.04)	
highway rays in 1999		-0.012
		(0.028)
N	237	237
First stage F	7.28	12.6

- Regressions exclude prefecture lights levels and growth
- No GDP data from before 1990

Heterogeneity by Region

	∆ln(CC Pop) 1990-2010 (1)	∆ln(CC Pop) 1990-2000 (2)	∆ln(CC Ind GDP) 1990-2005 (3)	∆ln(CC GDP) 1990-2005 (4)
highway rays in 2010 or 1999	-0.060*	-0.049***		
	(0.032)	(0.015)		
highway rays X Middle or West	0.026	0.0042		
	(0.039)	(0.024)		
railroad rays in 2005			-0.45***	-0.22***
			(0.12)	(0.086)
railroad rays X Middle or West			0.30*	0.095
			(0.17)	(0.11)
N	210	257	187	205
First stage F	11.5	9.22	12.8	17.9

- Middle/West Region has significantly smaller effects of railroads on industrial GDP location

Implications for the Extent to Which Transport Infrastructure Has Accommodated Urbanization

- Results apply to the 205 cities for which we could construct consistent population and GDP data collectively

2010 Infrastructure			Associated Core City Accommodation of (2010 or 2005 Totals)		
Highway Rays	Railroad Rays	Ring Road Outside City	Population (millions)	Industrial GDP (100 millions)	Total GDP (100 millions)
609	369	44	49.7	1706.4	1793.8
		1990 Aggregates	203.9	2,166	3,698
		2005/2010 Agg	316.3	24788.8	49349.2
		Percent of 1990	24%	79%	49%
		Pct of 2005/2010	16%	7%	4%

Implications for the Impacts of Additional Potential Infrastructure Construction

- 205 city sample

	Population	Industrial GDP	Total GDP
1 Additional Radial Highway	17.1	0	0
1 Additional Radial Railroad	0	6,941	8,883
Giving All Cities Without One a Ring Road	50.3	14,969	17,353
At least 3 Highway and 2 Railroad Rays	9.8	3,269	4,011
At least 3 Highway and 2 Railroad Rays & Ring Road	60.1	18,237	21,363
1990 Actual Aggregates	203.9	2,166	3,698
2005/2010 Actual Aggregates	316.3	24,789	49,349

Conclusions

- Highway rays have significantly influenced population decentralization in China

- Railroad rays have significantly influenced GDP decentralization

- Ring roads have significantly influenced both

- As a result, Chinese cities have been able to accommodate more residents and production activity

    - This has been important for the growth of Chinese cities and the Chinese economy overall