The Effect of Transport Infrastructure on India's Urban and Rural Development

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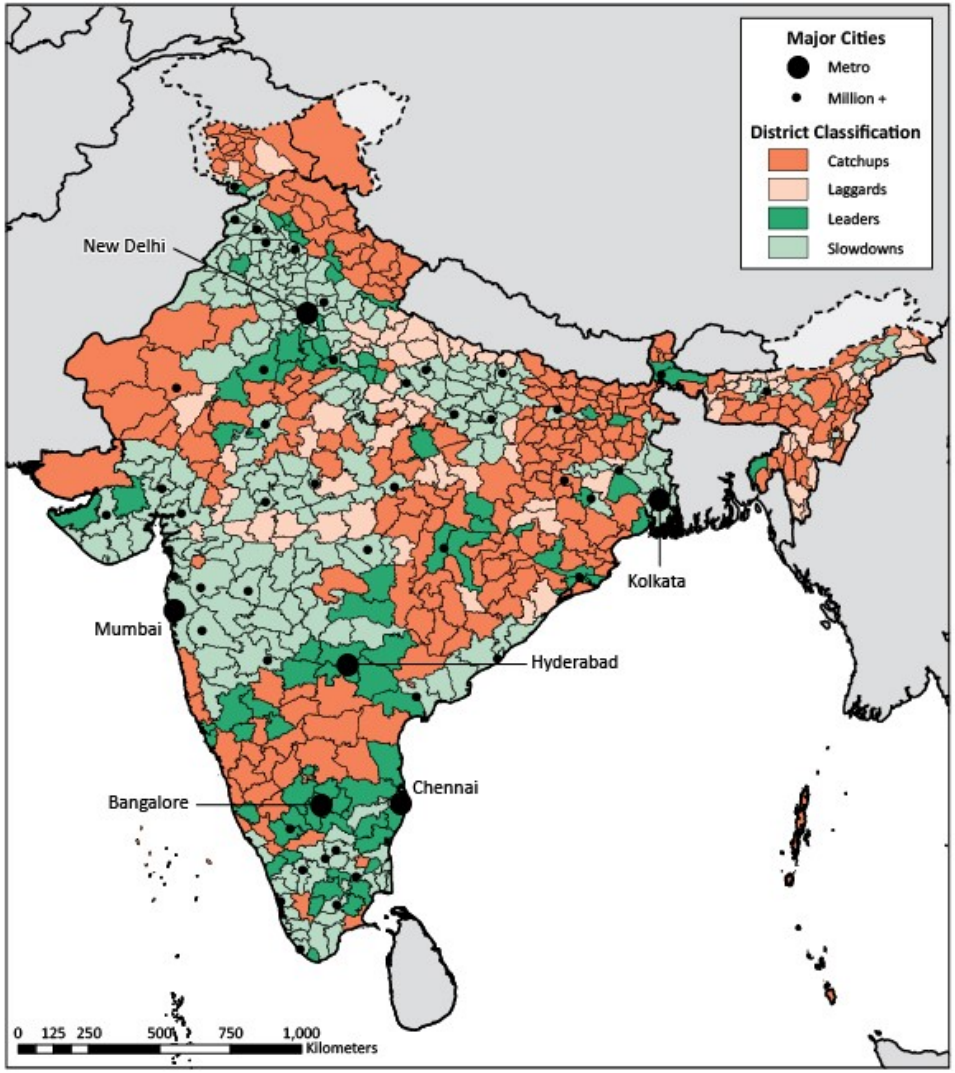
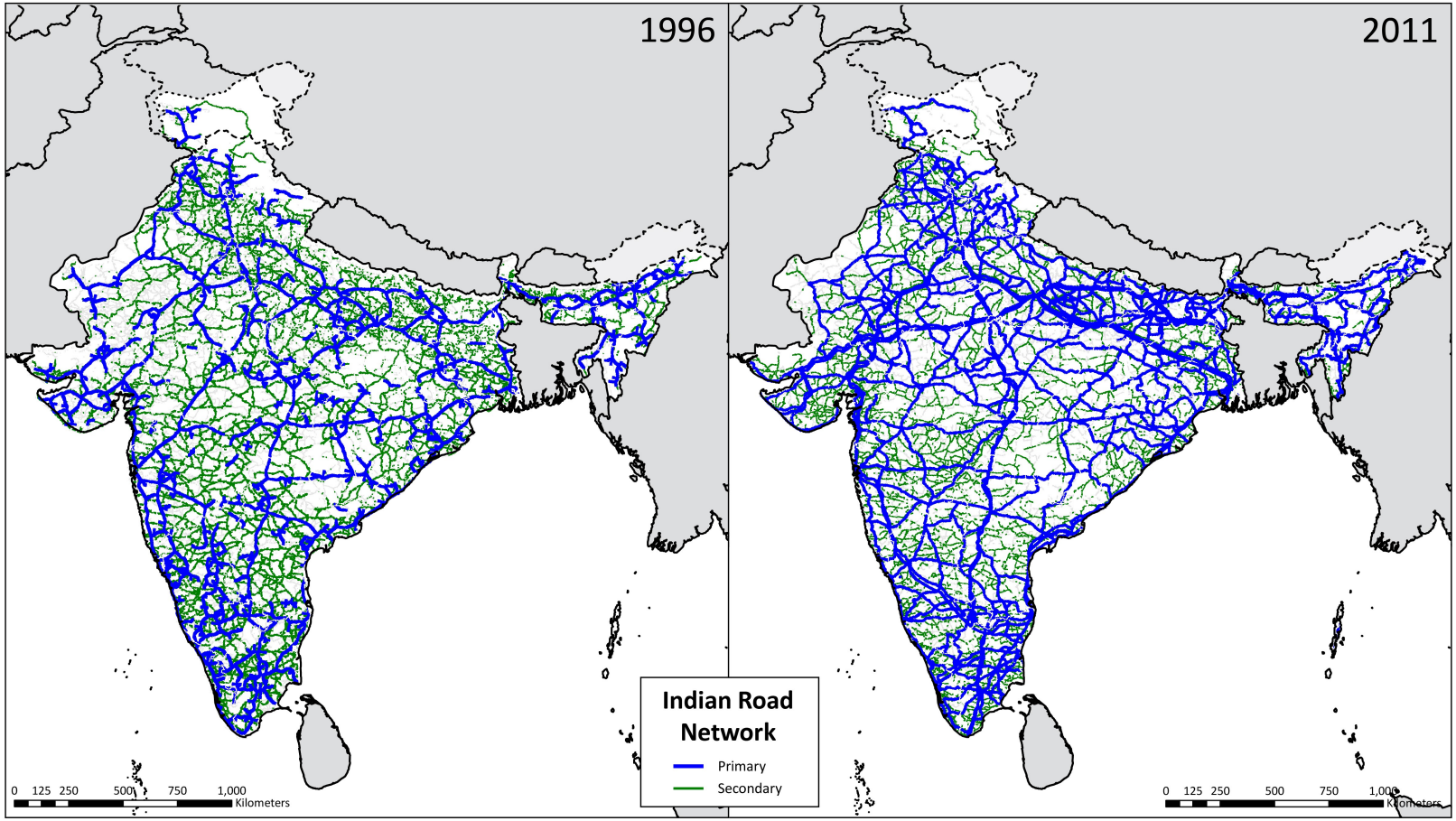
Outline

Where did growth take place in India?



Source: Tewari et al. (2017); Light data 1992-2013

How did changes in the road network contribute to growth?



Source: Alder et al. (2017), Allen and Atkin (2016)

This Paper

- This paper analyses the link between transport infrastructure investments and growth at the sub-district level
- We ask three questions

1. What is the role of transport infrastructure for growth?
   - ⇒ Estimate the effect of changes in the highway network through market access
   - ⇒ Based on digitization and color recognition of road maps & light data
2. How does the effect differ for urban and rural locations?
   - ⇒ Consider urban and rural locations separately
   - ⇒ Two-sector model with urban and rural locations
3. Does the effect depend on local characteristics?
   - ⇒ Interaction effects with local characteristics such as geography, human capital, and environment

Literature

- **India's spatial development:** Das et al. (2014); Desmet et al. (2015); Harari (2016); Tewari et al. (2017)
- **Transportation and development in India:** Datta (2012); Van Leemput (2015); Ghani et al. (2016); Khanna (2016); Asturias et al. (2016); Allen and Atkin (2016); Asher and Novosad (2016); Alder (2017)
- **Transportation and development in other countries:** Roberts et al. (2012); Donaldson and Hornbeck (2016); Jedwab and Storeyguard (2016); Bosker et al. (2015), Blankespoor et al. (2017), etc.

Outline

Income and Market Access

- Transport infrastructure can have spillover effects on non-targeted regions
  - ⇒ Challenging to evaluate the effect
- We estimate the effect of transport infrastructure based on a general equilibrium trade model
  - Donaldson and Hornbeck (2016)
- Predicts simple relationship between real income and 'market access'

$$\ln(\tilde{Y}_{o,t}) = \phi_o + \delta_{s,t} + \beta \ln\left(MA_{o,t}\right) + \chi \ln\left(R_{o,t}\right) + \eta \ln\left(H_{o,t}\right) + \varepsilon_{o,t}$$

- Can be estimated using changes in trade costs due to transport infrastructure
  - ⇒ Effect of infrastructure captured by market access

$$MA_o \approx \sum_d \frac{Y_d^i}{\tau_{od}^\theta}$$

Urban and Rural Sectors

- However, the standard one-sector G.E. model predicts that the effect of transport infrastructure is constant in initial income and endowments
  - Recall:

$$\ln(\tilde{Y}_{o,t}) = \phi_o + \delta_{s,t} + \beta \ln\left(MA_{o,t}\right) + \chi \ln\left(R_{o,t}\right) + \eta \ln\left(H_{o,t}\right) + \varepsilon_{o,t}$$

  - Based on Cobb-Douglas production with constant factor shares

  ⇒ Does not predict heterogeneous effects
- We therefore use a two sector version with urban and rural locations based on the extension in Donaldson and Hornbeck (2016)

  ⇒ Urban locations and rural locations are allowed to produce with different production functions (e.g. higher intensity of land in urban production)

  ⇒ Predicts heterogeneous effects

Preferences and Production

Urban and Rural Goods

- Consumers weigh rural goods with μ and urban goods with $1-\mu$,

$$U_o = \left(C^{Rural}\right)^{\mu}\left(C^{Urban}\right)^{1-\mu},$$

  where C^{Rural} and C^{Urban} are composites of urban and rural varieties
- Each location o produces varieties with a Cobb–Douglas technology

$$x_o^i(j) = z_o^i(j)\left(R_o(j)\right)^{\alpha_i}\left(H_o(j)\right)^{\gamma_i}\left(K_o(j)\right)^{1-\alpha_i-\gamma_i}.$$

  using local resources (R), human capital (H), and physical capital (K), and productivity z_o^i

$\Rightarrow$ Factor shares depend on sector $i \in \{Urban, Rural\}$

Urban and Rural Sectors

Empirical Implementation

- Solving for real income yields the following two regression equations
  - Rural real income (R)

$$\begin{aligned}\ln(\tilde{Y}^R_{o,t}) &= \phi^R_o + \delta^R_{s,t} + \beta^R \ln\left(FMA_{o,t}\right) + \xi \ln\left(CMA^R_{o,t}\right) + \omega \ln\left(CMA^U_{o,t}\right) \\ &+ \chi^R \ln\left(R_{o,t}\right) + \eta^R \ln\left(H_{o,t}\right) + \Psi X_{o,t} + \varepsilon^R_{o,t}\end{aligned}$$

  - Urban real income (U)

$$\begin{aligned}\ln(\tilde{Y}^U_{o,t}) &= \phi^U_o + \delta^U_{s,t} + \beta^U \ln\left(FMA_{o,t}\right) + \xi \ln\left(CMA^R_{o,t}\right) + \omega \ln\left(CMA^U_{o,t}\right) \\ &+ \chi^U \ln\left(R_{o,t}\right) + \eta^U \ln\left(H_{o,t}\right) + \Psi X_{o,t} + \varepsilon^U_{o,t}.\end{aligned}$$

$\Rightarrow$ Each location's income depends on

1. Firm Market Access: firms' access to 'exports'
2. Rural Consumer Market Access: consumers' access to rural goods
3. Urban Consumer Market Access: consumers' access to urban goods

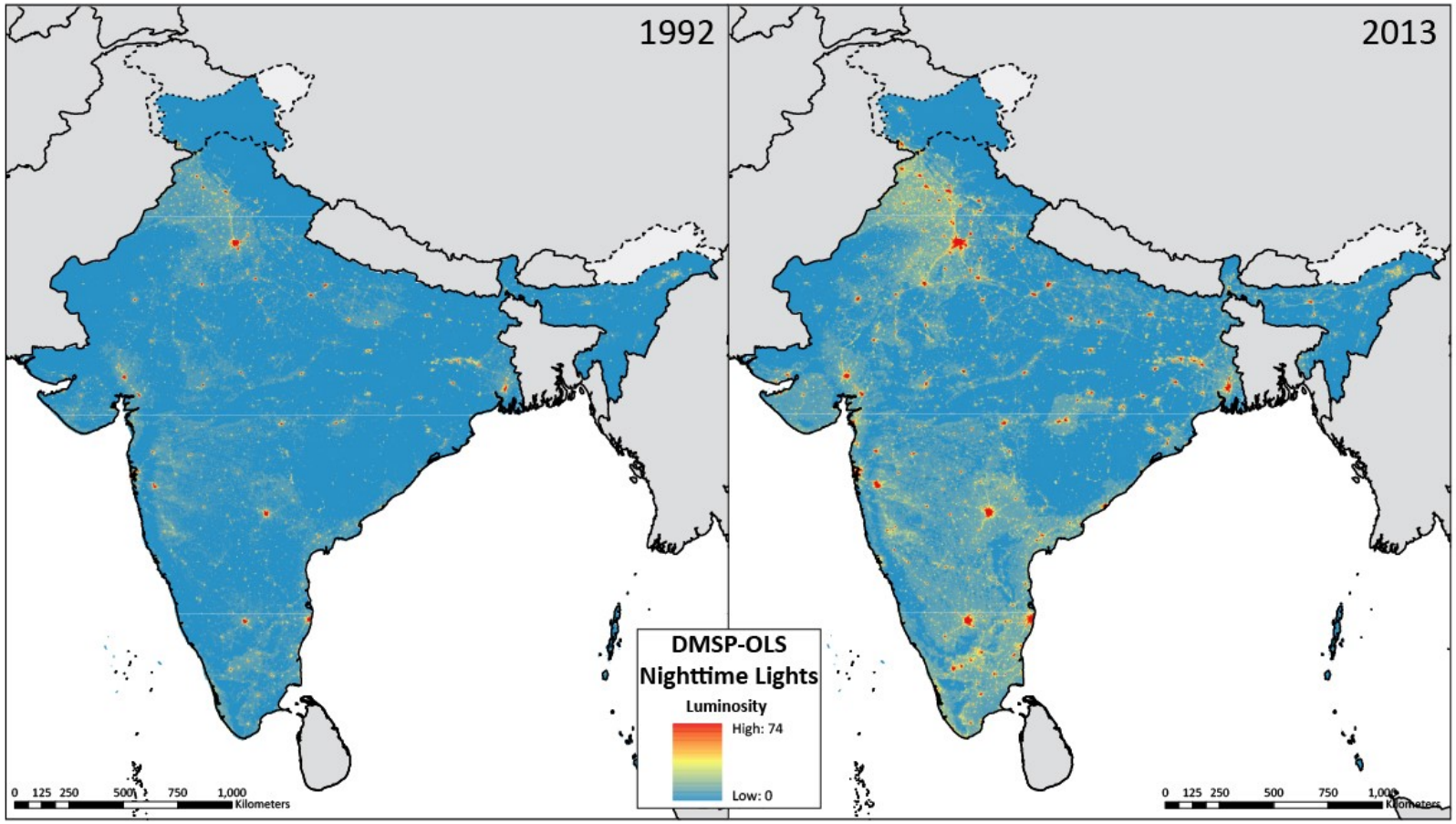
Outline

Data

- Light data from 1992 to 2013 for 5,990 sub-districts
  - ⇒ Classify sub-districts as urban if light density>33
- Urban and rural population
  - ⇒ Alternative: classify sub-districts based on official classification
- Road maps from Allen and Atkin (2016) for 1962, 1969, 1977, 1988, 1996, 2004, 2011
  - ⇒ Scan and digitize using color recognition algorithm
- Social and environmental variables
  - ⇒ World Bank South Asia database

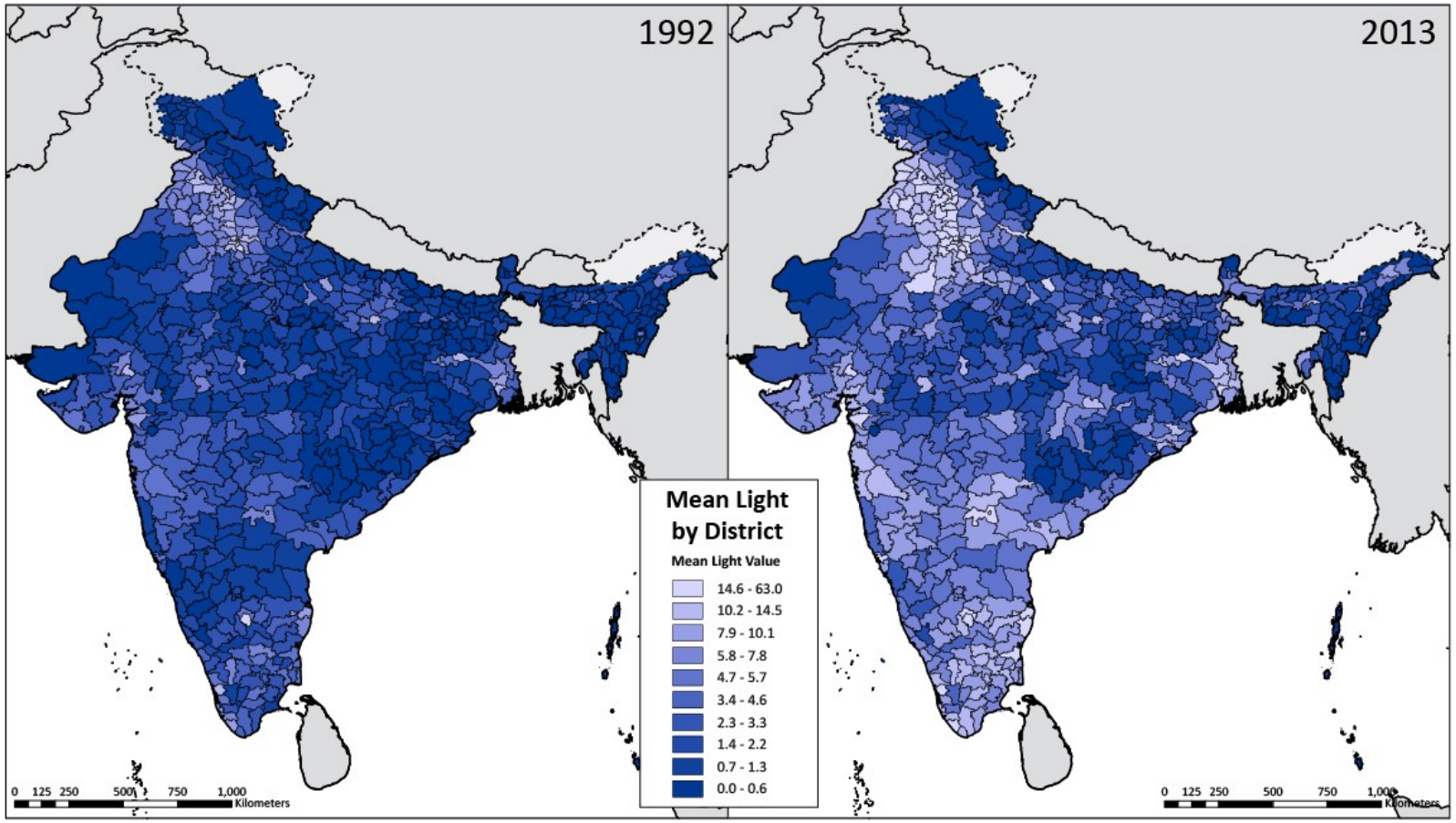
Light density in 1992 and 2013

Pixel-level

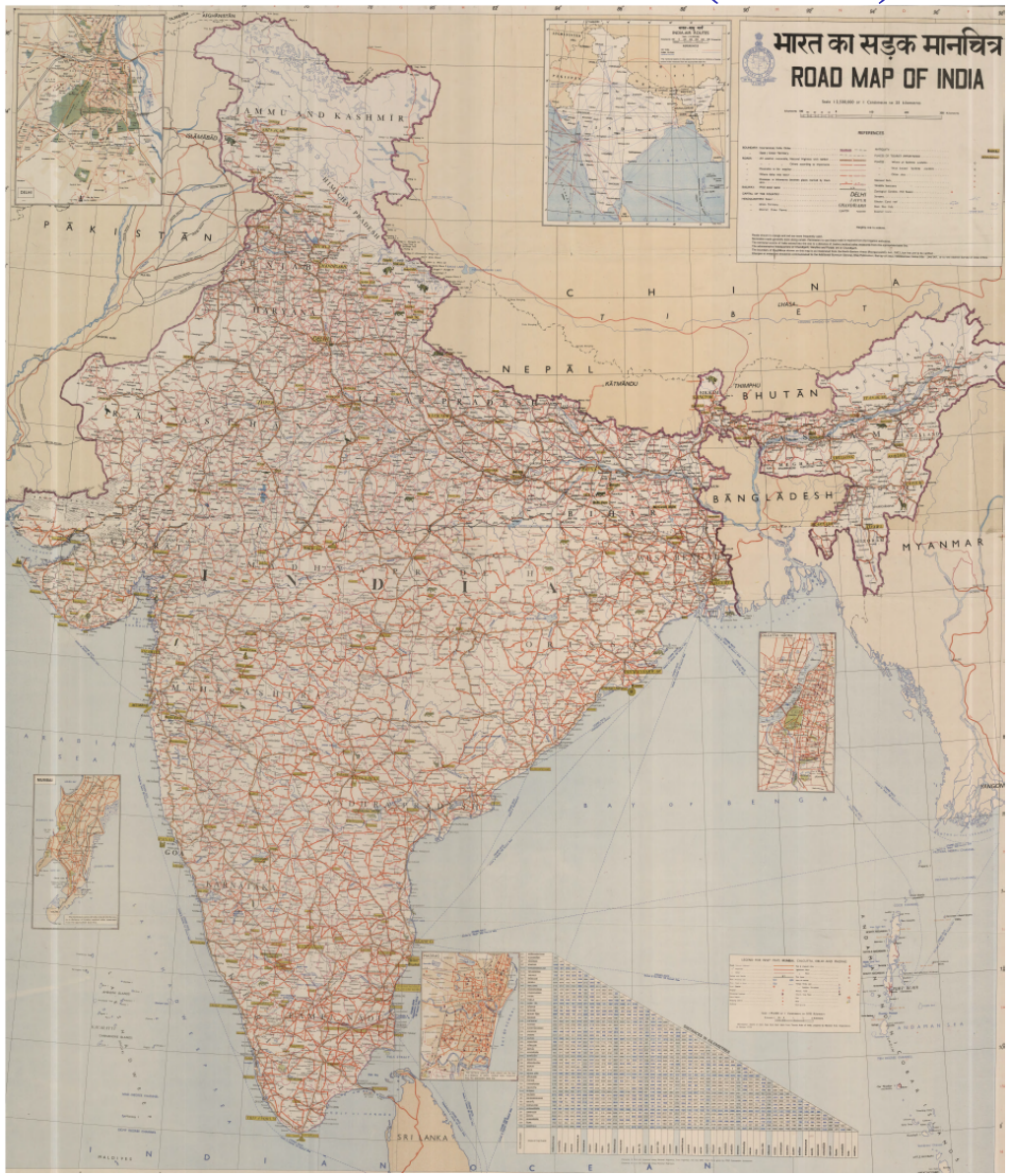


Light density in 1992 and 2013

District-level



Indian Road Atlas (1996)



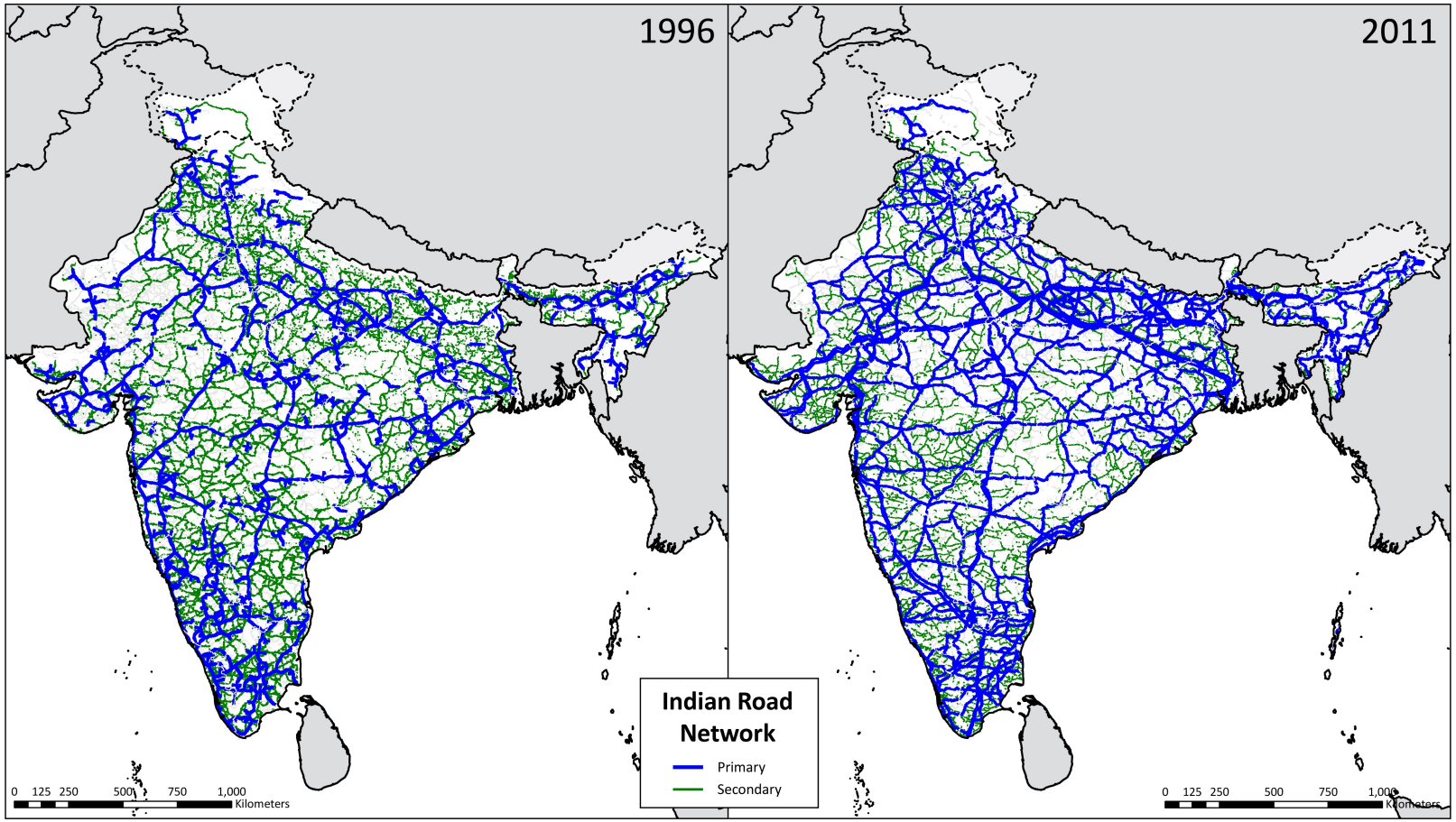
Source: Allen and Atkin (2016)

Indian Road Atlas (1996)

Source: Allen and Atkin (2016)

Evolution of the road network over time

Based on Color Recognition



Source: Alder et al. (2017), Allen and Atkin (2016)

Outline

Results overview

1. One-sector model
   - ⇒ Effect of market access on income
2. Restrict sample to urban and rural districts
   - ⇒ Total market access has larger effect on urban locations (conditional on controls) but not precisely estimated
3. Interaction effects with local characteristics
   - ⇒ Main effect remains relatively stable
   - ⇒ Mixed evidence for interaction effects
4. Two sector version
   - ⇒ Urban and rural market access individually have similar effect
   - ⇒ Highly correlated and cannot empirically separate their effect
   - ⇒ Interaction effects may depend on sector (e.g. literacy, groundwater)
5. Full general equilibrium model (see paper)

Main effect of market access for urban and rural sample

Approximation of market access

	(1) Full	(2) Urban	(3) Rural	(4) Full	(5) Urban	(6) Rural
Market Access	1.007***	0.696	0.846**	0.626**	0.630	0.338
	(3.02)	(1.09)	(2.21)	(2.08)	(1.00)	(0.99)
Initial market access	1.587***	0.771	1.625***	1.029***	0.695	0.892***
	(3.73)	(1.26)	(3.04)	(3.46)	(1.13)	(2.70)
Log mean light in 1999	-0.129***	-0.135***	-0.147***	-0.104***	-0.0814**	-0.112***
	(-10.52)	(-5.41)	(-8.93)	(-6.55)	(-2.13)	(-6.20)
Pre-trend				-0.0386**	0.0294	-0.0494**
				(-2.11)	(0.60)	(-2.55)
Top Coded				-0.0485	-0.00658	0
				(-1.25)	(-0.15)	(.)
Urban share				0.0325	-0.165*	0
				(0.54)	(-1.77)	(.)
Growth in literacy rate				0.0569	-0.0841	0.0182
				(0.42)	(-0.32)	(0.11)
N	5343	1149	4131	4842	1149	3693
adj. R^2	0.536	0.643	0.556	0.573	0.647	0.594

The dependent variable is growth in light at the sub-district level from 1999 to 2012 (averaging start and end years). The market access measures are based on the approximation. All regressions control for sub-district fixed effects and district-year fixed effects. Standard errors are clustered at the district level. t values reported in parenthesis. Significance levels are: * 0.10, ** 0.05, *** 0.01.

Interaction effects

Urban, literacy, distance to large city

	(1)	(2)	(3)	(4)	(5)	(6)
Market Access	0.619**	0.633**	0.657**	0.539*	0.606**	0.586**
	(2.06)	(1.98)	(2.18)	(1.77)	(2.09)	(2.02)
Initial market access	1.026***	1.025***	0.972***	0.985***	1.017***	0.874***
	(3.46)	(3.48)	(3.36)	(3.34)	(3.47)	(3.14)
Log mean light in 1999	-0.105***	-0.105***	-0.104***	-0.104***	-0.105***	-0.101***
	(-6.85)	(-6.82)	(-6.81)	(-6.80)	(-6.81)	(-6.60)
Pre-trend	-0.0380**	-0.0378**	-0.0363*	-0.0374**	-0.0376**	-0.0356*
	(-2.05)	(-2.02)	(-1.94)	(-2.01)	(-1.99)	(-1.91)
Top coded	-0.0494	-0.0501	-0.0510	-0.0564	-0.0499	-0.0678*
	(-1.27)	(-1.28)	(-1.32)	(-1.46)	(-1.28)	(-1.73)
Urban share	0.0315	0.0303	0.0222	0.0320	0.0308	0.0376
	(0.52)	(0.50)	(0.37)	(0.53)	(0.50)	(0.62)
Market access * Urban (population)		-0.0387				
		(-0.19)				
Market access * Urban (light)			-0.594***			
			(-2.74)			
Market access * City Distance				0.237		
				(1.12)		
Market access * Literacy (2001)					-0.00222	
					(-0.16)	
Market access * Mean light						-0.383**
						(-2.42)
N	4842	4841	4842	4842	4842	4842
adj. R^2	0.573	0.573	0.574	0.573	0.573	0.576

The dependent variable is growth in light at the sub-district level from 1999 to 2012 (averaging start and end years). The market access measures are based on the approximation. All regressions control for sub-district fixed effects and district-year fixed effects. Standard errors are clustered at the district level. t values reported in parenthesis. Significance levels are: * 0.10, ** 0.05, *** 0.01.

Interaction effects

Land characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
Market Access	0.619**	0.616**	0.624**	0.640**	0.634**	0.507*
	(2.06)	(2.02)	(2.08)	(2.13)	(2.10)	(1.71)
Initial market access	1.026***	1.026***	1.024***	1.028***	1.030***	0.888***
	(3.46)	(3.46)	(3.47)	(3.51)	(3.47)	(3.03)
Log mean light in 1999	-0.105***	-0.105***	-0.105***	-0.105***	-0.105***	-0.0986***
	(-6.85)	(-6.85)	(-6.85)	(-6.86)	(-6.86)	(-6.30)
Pre-trend	-0.0380**	-0.0379**	-0.0382**	-0.0378**	-0.0378**	-0.0381**
	(-2.05)	(-2.05)	(-2.07)	(-2.05)	(-2.05)	(-2.00)
Top coded	-0.0494	-0.0496	-0.0495	-0.0507	-0.0500	-0.0523
	(-1.27)	(-1.28)	(-1.27)	(-1.30)	(-1.28)	(-1.33)
Urban share	0.0315	0.0311	0.0312	0.0327	0.0327	0.0195
	(0.52)	(0.52)	(0.52)	(0.54)	(0.54)	(0.32)
Market access * Cropland		0.000399				
		(0.09)				
Market access * Forest			0.00489			
			(0.36)			
Market access * Elevation				0.000838		
				(1.25)		
Market access * Roughness					0.00104	
					(0.79)	
Market access * Groundwater						0.00776
						(0.13)
N	4842	4842	4842	4842	4842	4653
adj. R^2	0.573	0.573	0.573	0.574	0.573	0.565

The dependent variable is growth in light at the sub-district level from 1999 to 2012 (averaging start and end years). The market access measures are based on the approximation. All regressions control for sub-district fixed effects and district-year fixed effects. All variables are at the sub-district level except for groundwater, which is a district-level variables. Standard errors are clustered at the district level. t values reported in parenthesis. Significance levels are: * 0.10, ** 0.05, *** 0.01.

Interaction effects

Temperature and precipitation

	(1)	(2)	(3)	(4)	(5)
Market Access	0.619**	0.647**	0.616**	0.964***	0.638**
	(2.06)	(2.05)	(2.01)	(2.79)	(2.07)
Initial market access	1.026***	1.028***	1.026***	1.077***	1.021***
	(3.46)	(3.45)	(3.45)	(3.63)	(3.48)
Log mean light in 1999	-0.105***	-0.105***	-0.105***	-0.106***	-0.105***
	(-6.85)	(-6.85)	(-6.84)	(-6.90)	(-6.86)
Pre-trend	-0.0380**	-0.0381**	-0.0379**	-0.0398**	-0.0386**
	(-2.05)	(-2.06)	(-2.05)	(-2.15)	(-2.08)
Top coded	-0.0494	-0.0495	-0.0494	-0.0501	-0.0505
	(-1.27)	(-1.27)	(-1.27)	(-1.29)	(-1.30)
Urban share	0.0315	0.0316	0.0315	0.0300	0.0324
	(0.52)	(0.52)	(0.52)	(0.50)	(0.54)
Market access * Mean precipitation		0.00163			
		(0.28)			
Market access * Precipitation deviation			-0.000600		
			(-0.04)		
Market access * Mean temperature				-0.254**	
				(-2.48)	
Market access * Temperature deviation					1.095
					(0.63)
N	4842	4842	4842	4842	4842
adj. R^2	0.573	0.573	0.573	0.574	0.573

The dependent variable is growth in light at the sub-district level from 1999 to 2012 (averaging start and end years). The market access measures are based on the approximation. All regressions control for sub-district fixed effects and district-year fixed effects. Standard errors are clustered at the district level. t values reported in parenthesis. Significance levels are: * 0.10, ** 0.05, *** 0.01.

Main effects in one-sector model and interaction effects

Takeaways

- Main effect of one-sector market access measure
  - Yields an elasticity of income with respect to market access of about 0.6 in the full sample
  - Similar for urban sub-sample, but insignificant
  - Smaller for rural subsample, and insignificant
- Interaction effects
  - Main effect is relatively stable when allowing for interaction effects
  - Some evidence that effect of market access is falling in initial level of urbanization and light density
  - No significant interactions with land characteristics and precipitation, some evidence of negative interaction with temperature

Urban and rural market access

	(1) Full	(2) Full	(3) Full	(4) Urban	(5) Urban	(6) Urban	(7) Rural	(8) Rural	(9) Rural
Urban market access	-0.416	1.031***		-1.760	0.695		1.038	0.873**	
	(-0.19)	(3.03)		(-0.48)	(1.06)		(0.37)	(2.20)	
Rural market access	1.400		1.006***	2.473		0.743	-0.159		0.817**
	(0.67)		(3.09)	(0.72)		(1.19)	(-0.06)		(2.19)
Initial urban market access	-0.431	0.203	-0.250	-1.149	0.0194	-0.324	1.157	1.084	0.708
	(-0.32)	(0.22)	(-0.27)	(-0.59)	(0.01)	(-0.20)	(0.66)	(0.90)	(0.59)
Initial rural market access	1.991	1.363	1.814**	1.888	0.713	1.071	0.479	0.551	0.918
	(1.51)	(1.63)	(2.11)	(0.94)	(0.45)	(0.67)	(0.28)	(0.51)	(0.83)
Log mean light in 1999	-0.130***	-0.129***	-0.130***	-0.138***	-0.136***	-0.137***	-0.147***	-0.147***	-0.147***
	(-10.56)	(-10.52)	(-10.54)	(-5.51)	(-5.42)	(-5.45)	(-8.90)	(-8.90)	(-8.90)
N	5343	5343	5343	1149	1149	1149	4131	4131	4131
adj. R^2	0.536	0.536	0.536	0.642	0.642	0.643	0.555	0.556	0.556

The dependent variable is growth in light at the sub-district level from 1999 to 2012 (averaging start and end years). The market access measures are based on the approximation. All regressions control for sub-district fixed effects and district-year fixed effects. Standard errors are clustered at the district level. t values reported in parenthesis. Significance levels are: * 0.10, ** 0.05, *** 0.01.

Urban and rural market access

Joint estimation and controls

	(1) Full	(2) Urban	(3) Rural	(4) Full	(5) Urban	(6) Rural
Urban market access	0.170	-1.988	1.035	0.162	-1.985	1.032
	(0.08)	(-0.55)	(0.38)	(0.08)	(-0.55)	(0.38)
Rural market access	0.461	2.643	-0.643	0.477	2.644	-0.637
	(0.24)	(0.78)	(-0.26)	(0.24)	(0.78)	(-0.26)
Initial urban market access	-0.470	-1.746	0.280	-0.489	-1.719	0.275
	(-0.36)	(-0.86)	(0.16)	(-0.37)	(-0.84)	(0.16)
Initial rural market access	1.465	2.387	0.598	1.487	2.365	0.604
	(1.15)	(1.14)	(0.36)	(1.17)	(1.13)	(0.37)
Log mean light in 1999	-0.105***	-0.0806**	-0.112***	-0.104***	-0.0816**	-0.112***
	(-6.83)	(-2.03)	(-6.41)	(-6.51)	(-2.07)	(-6.14)
Pre-trend	-0.0383**	0.0284	-0.0498**	-0.0391**	0.0302	-0.0501**
	(-2.07)	(0.60)	(-2.51)	(-2.13)	(0.62)	(-2.57)
Top coded	-0.0504	-0.0102	0	-0.0494	-0.0104	0
	(-1.30)	(-0.24)	(.)	(-1.28)	(-0.24)	(.)
Urban share	0.0216	-0.166*	0	0.0225	-0.170*	0
	(0.35)	(-1.75)	(.)	(0.36)	(-1.76)	(.)
Growth in literacy rate				0.0632	-0.0723	0.0199
				(0.47)	(-0.28)	(0.12)
N	4842	1149	3693	4842	1149	3693
adj. R^2	0.573	0.647	0.594	0.573	0.647	0.594

The dependent variable is growth in light at the sub-district level from 1999 to 2012 (averaging start and end years). The market access measures are based on the approximation. All regressions control for sub-district fixed effects and district-year fixed effects. Standard errors are clustered at the district level. t values reported in parenthesis. Significance levels are: * 0.10, ** 0.05, *** 0.01.

Urban and rural market access

Takeaways

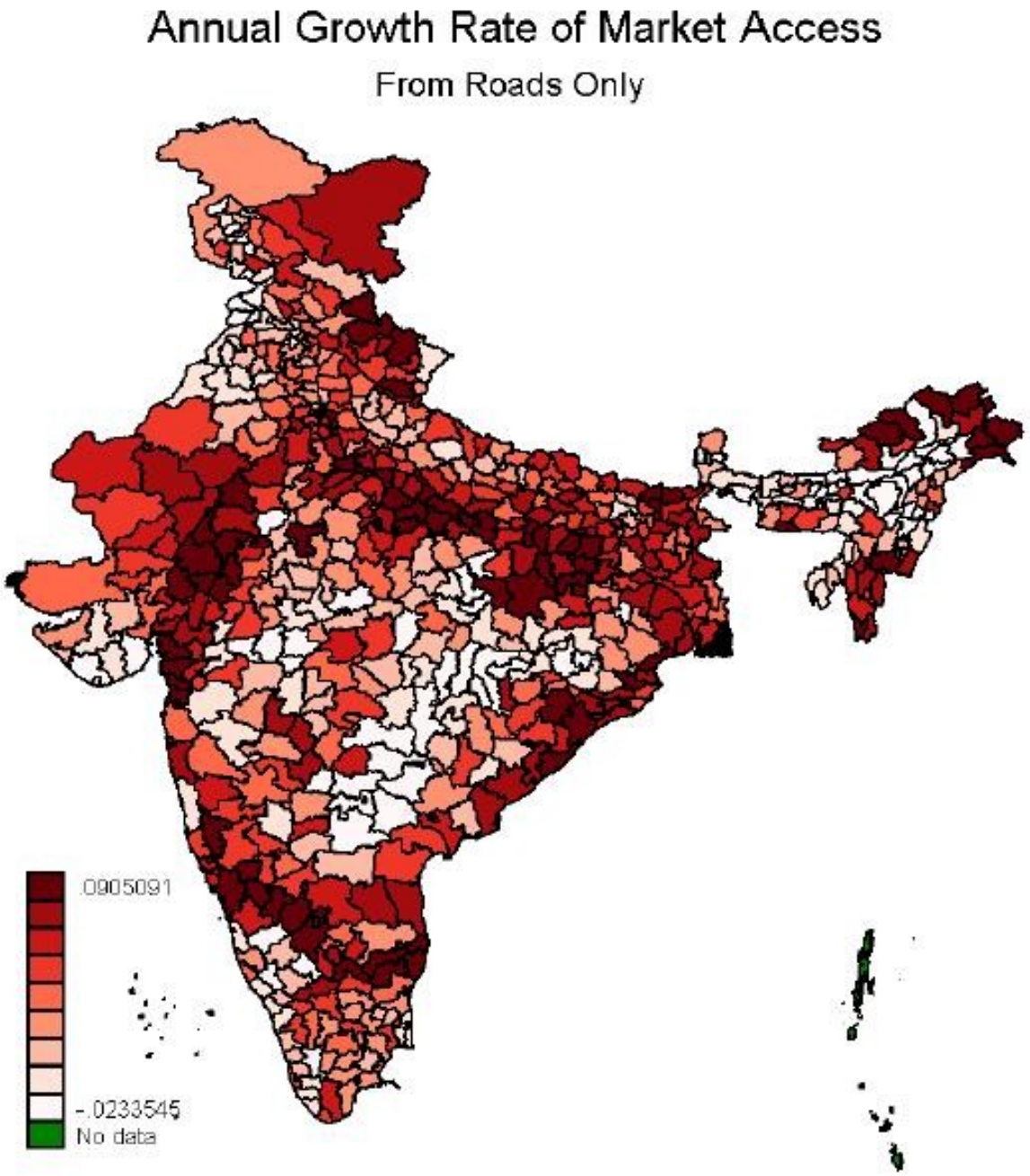
- Two sector model with approximations of market access
  - Urban and rural market access individually have similar effects
  - Highly correlated and difficult to empirically separate their effects
  - Heterogeneous effects might depend on sector (e.g. literacy, groundwater)
- General equilibrium market access measures based on full system of equations
  - Difficult to empirically separate effects of urban and rural consumer market access and firm market access, but firm market access seems the strongest (see paper)

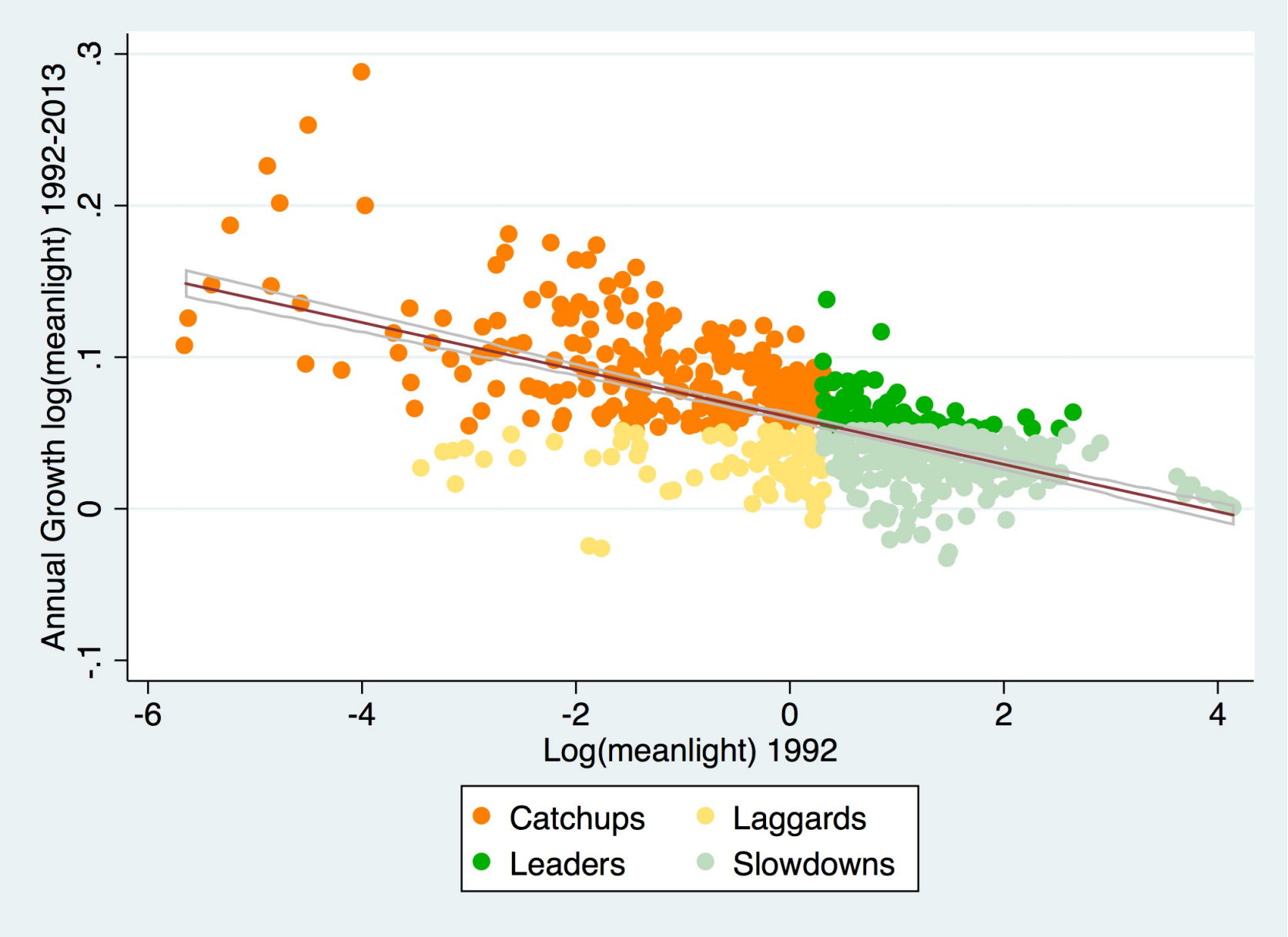
Outline

Conclusion

- Approach
  - We estimate the effect of transport infrastructure investments on growth at sub-district level using a two-sector general equilibrium trade model
  - Digitize historical road maps with color recognition
  - Construct rich dataset with variables on light density, land characteristics, population, etc
- Results
  - Transport infrastructure has contributed to growth in India
    - ⇒ Through the reduction in trade costs and increase in market access
  - Main effect of market access is robust to inclusion of interaction effects
  - Mixed evidence of heterogeneous effects
    - ⇒ Urbanization, literacy, land characteristics, climate
  - Urban and rural market access difficult to separate empirically
- Implications for future work
  - Need data on urban and rural outcomes at high spatial resolution
  - Separate effect of urban and rural infrastructure

Outline


Annual Growth Rate of Market Access
From Roads Only
.0905091
-.0233545
No data


Annual Growth log(meanlight) 1992-2013
.3
.2
.1
0
-.1
-6
-4
-2
0
2
4
Log(meanlight) 1992
Catchups
Laggards
Leaders
Slowdowns

Preferences and Production

- Consumers weigh rural goods with μ and urban goods with $1-\mu$,

$$U_o = \left(C^R\right)^{\mu}\left(C^U\right)^{1-\mu},$$

where $C^R = \left(\int_j x_o^R(j)^{\frac{\sigma_R-1}{\sigma_R}} dj\right)^{\frac{\sigma_R}{\sigma_R-1}}$ and $C^U = \left(\int_j x_o^U(j)^{\frac{\sigma_U-1}{\sigma_U}} dj\right)^{\frac{\sigma_U}{\sigma_U-1}}$ are composites of urban and rural varieties indexed by j

- Each location produces varieties with a Cobb–Douglas technology

$$x_o^i(j) = z_o^i(j)\left(R_o(j)\right)^{\alpha_i}\left(H_o(j)\right)^{\gamma_i}\left(K_o(j)\right)^{1-\alpha_i-\gamma_i}.$$

using local resources (R), human capital (H), and physical capital (K), and productivity z_o^i

Marginal costs, trade costs, and prices

- Since we assume perfect competition, prices equal the marginal costs of producing each variety:

$$
\begin{aligned}
p^i_{oo}(j) &= MC^i_o(j) = \frac{q_o^{\alpha_i} w_o^{\gamma_i} r_o^{1-\alpha_i-\gamma_i}}{z^i_o(j)} \\
p^i_{od}(j) &= \tau_{od} MC^i_o(j) = \tau_{od} \frac{q_o^{\alpha_i} w_o^{\gamma_i} r_o^{1-\alpha_i-\gamma_i}}{z^i_o(j)} \\
z^i_o(j) &= \tau_{od} \frac{q_o^{\alpha_i} w_o^{\gamma_i} r_o^{1-\alpha_i-\gamma_i}}{p^i_{od}(j)}
\end{aligned}
$$

Gravity equation

- The gravity equation yields (Eaton and Kortum, 2002; Donaldson and Hornbeck, 2016)

$$X^i_{od} = \underbrace{T^i_o \left(q_o^{\alpha_i} w_o^{\gamma_i}\right)^{-\theta}}_{\text{Origin}} \times \underbrace{X^i_d}_{\text{Destination}} \times \underbrace{\tau_{od}^{-\theta}}_{\text{Trade costs}} \times \underbrace{\kappa^i_1 (CMA^i_d)^{-1}}_{\text{Destination's CMA}} .$$

- Aggregating over all exports yields the total production (= income) of each location

$$Y^i_o = \sum_{d \in \mathcal{U}, \mathcal{R}} X^i_{od} = \kappa^i_1 T^i_o (q_o^{\alpha_i} w_o^{\gamma_i})^{-\theta} \sum_{d \in \mathcal{U}, \mathcal{R}} \left[\tau_{od}^{-\theta} (CMA^i_d)^{-1} X^i_d\right].$$

Real income

- Using definitions for consumer market access (in each sector) and firm market access, we obtain

$$
\begin{aligned}
\tilde{Y}_o^i &\equiv \frac{Y_o^i}{(P_o^R)^{\mu}(P_o^U)^{1-\mu}} \\
&= \left(\kappa_1 T_o^i\right)^{\frac{1}{1+\theta\alpha_i+\theta\gamma_i}} \left(\frac{\alpha_i}{R_o}\right)^{\frac{-\theta\alpha_i}{1+\theta\alpha_i+\theta\gamma_i}} \left(\frac{\gamma_i}{H_o}\right)^{\frac{-\theta\gamma_i}{1+\theta\alpha_i+\theta\gamma_i}} \\
&\quad \left(FMA_o^i\right)^{\frac{1}{1+\theta\alpha_i+\theta\gamma_i}} \left((CMA_d^R)^{-\frac{1}{\theta}}\right)^{-\mu} \left((CMA_d^U)^{-\frac{1}{\theta}}\right)^{-(1-\mu)}.
\end{aligned}
$$

Real income II

- Taking logs yields

$$
\begin{aligned}
\ln(\tilde{Y}_o^i) &= \frac{1}{1+\theta(\alpha_i+\gamma_i)} \ln\left(\kappa_1 T_o^i\right) \\
&+ \frac{\theta\alpha_i}{1+\theta(\alpha_i+\gamma_i)} \ln\left(\frac{R_o}{\alpha_i}\right) + \frac{\theta\gamma_i}{1+\theta(\alpha_i+\gamma_i)} \ln\left(\frac{H_o}{\gamma_i}\right) \\
&+ \frac{1}{1+\theta(\alpha_i+\gamma_i)} \ln\left(FMA_o^i\right) \\
&+ \frac{\mu}{\theta} \ln(CMA_d^R) + \frac{(1-\mu)}{\theta} \ln(CMA_d^U).
\end{aligned}
$$

Versions of market access (general equilibrium)

- Substituting for nominal income and expenditures in the market access equations, we obtain

$$
\begin{aligned}
CMA_o^R &= \sum_{d\in\mathcal{R}} \tau_{od}^{-\theta}(FMA_d^R)^{-1}(CMA_d^R)^{-\frac{\mu}{\theta}}(CMA_d^U)^{-\frac{1-\mu}{\theta}}\tilde{Y}_d, o\in\mathcal{U},\mathcal{R} \\
CMA_o^U &= \sum_{d\in\mathcal{U}} \tau_{od}^{-\theta}(FMA_d^U)^{-1}(CMA_d^R)^{-\frac{\mu}{\theta}}(CMA_d^U)^{-\frac{1-\mu}{\theta}}\tilde{Y}_d, o\in\mathcal{U},\mathcal{R} \\
FMA_o^R &= \sum_{d\in\mathcal{U},\mathcal{R}} \tau_{od}^{-\theta}(CMA_d^R)^{-\frac{\theta+\mu}{\theta}}(CMA_d^U)^{-\frac{1-\mu}{\theta}}\mu\tilde{Y}_d, o\in\mathcal{R} \\
FMA_o^U &= \sum_{d\in\mathcal{U},\mathcal{R}} \tau_{od}^{-\theta}(CMA_d^U)^{-\frac{\theta+1-\mu}{\theta}}(CMA_d^R)^{-\frac{\mu}{\theta}}(1-\mu)\tilde{Y}_d, o\in\mathcal{U}
\end{aligned}
$$

Approximated market access

$$
\begin{aligned}
MA_o^R &\approx \sum_{d \neq o \in \mathcal{R}} \frac{Y_d^i}{\tau_{od}^\theta} \\
MA_o^U &\approx \sum_{d \neq o \in \mathcal{U}} \frac{Y_d^i}{\tau_{od}^\theta} \\
MA_o &\approx \sum_{d \in \mathcal{R},\mathcal{U}} \frac{Y_d^i}{\tau_{od}^\theta}
\end{aligned}
$$

Table: Interaction effects of urban and rural market access with urban dummy, literacy, and distance to large city

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Urban market Access	0.170	0.0206	0.340	0.554	0.111	-0.104	0.408
	(0.08)	(0.01)	(0.16)	(0.27)	(0.05)	(-0.05)	(0.20)
Rural market Access	0.461	0.606	0.337	0.122	0.440	0.768	0.175
	(0.24)	(0.31)	(0.17)	(0.06)	(0.22)	(0.39)	(0.09)
Initial urban market access	-0.470	-0.439	-0.308	0.00621	-0.514	-0.734	-0.252
	(-0.36)	(-0.33)	(-0.23)	(0.00)	(-0.39)	(-0.56)	(-0.20)
Initial rural market access	1.465	1.445	1.247	0.941	1.467	1.685	1.100
	(1.15)	(1.13)	(0.98)	(0.75)	(1.15)	(1.31)	(0.88)
Log mean light in 1999	-0.105***	-0.105***	-0.104***	-0.111***	-0.104***	-0.104***	-0.102***
	(-6.83)	(-6.80)	(-6.80)	(-7.71)	(-6.76)	(-6.74)	(-6.69)
Pre-trend	-0.0383**	-0.0376**	-0.0371**	-0.0357*	-0.0380**	-0.0399**	-0.0347*
	(-2.07)	(-2.00)	(-1.99)	(-1.93)	(-2.03)	(-2.11)	(-1.86)
Top coded	-0.0504	-0.0464	-0.0550	-0.0598	-0.0591	-0.0684*	-0.0624
	(-1.30)	(-1.17)	(-1.41)	(-1.53)	(-1.52)	(-1.68)	(-1.49)
Urban share	0.0216	0.0139	0.0158	0.0368	0.0218	0.0267	0.0289
	(0.35)	(0.22)	(0.26)	(0.63)	(0.35)	(0.43)	(0.46)
Urban market access * Urban (population)		0.414					
		(1.18)					
Rural market access * Urban (population)		-0.421					
		(-1.42)					
Urban market access * Urban (light)			-0.574**				
			(-2.18)				
Rural market access * Urban (light)			-0.0511				
			(-0.22)				
Urban market access * Urban (calib. light)				-0.540**			
				(-2.14)			
Rural market access * Urban (calib. light)				-0.111			
				(-0.49)			
Urban market access * City Distance					0.245		
					(0.74)		
Rural market access * City Distance					0.0151		
					(0.05)		
Urban market access * Literacy (2001)						-0.0434	
						(-1.65)	
Rural market access * Literacy (2001)						0.0351*	
						(1.71)	
Urban market access * Mean light							0.0309
							(0.08)
Rural market access * Mean light							-0.406
							(-1.19)
N	4842	4841	4842	4807	4842	4842	4842
adj. R^2	0.573	0.573	0.574	0.583	0.573	0.574	0.576

Table: Interaction effects of urban and rural market access with land characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Urban market access	0.170	0.157	0.163	0.396	0.732	0.192	0.205	-1.069
	(0.08)	(0.08)	(0.08)	(0.19)	(0.34)	(0.09)	(0.10)	(-0.51)
Rural market access	0.461	0.477	0.470	0.331	-0.182	0.444	0.441	1.497
	(0.24)	(0.25)	(0.24)	(0.17)	(-0.09)	(0.23)	(0.23)	(0.78)
Initial urban market access	-0.470	-0.500	-0.454	-0.556	-0.301	-0.279	-0.431	-0.951
	(-0.36)	(-0.38)	(-0.35)	(-0.43)	(-0.23)	(-0.21)	(-0.33)	(-0.76)
Initial rural market access	1.465	1.490	1.445	1.537	1.228	1.298	1.432	1.785
	(1.15)	(1.18)	(1.13)	(1.22)	(0.95)	(1.03)	(1.12)	(1.46)
Log mean light in 1999	-0.105***	-0.105***	-0.105***	-0.104***	-0.105***	-0.105***	-0.105***	-0.0985***
	(-6.83)	(-6.83)	(-6.76)	(-6.80)	(-6.79)	(-6.84)	(-6.83)	(-6.30)
Pre-trend	-0.0383**	-0.0383**	-0.0385**	-0.0387**	-0.0372**	-0.0381**	-0.0382**	-0.0385**
	(-2.07)	(-2.06)	(-2.08)	(-2.08)	(-2.00)	(-2.06)	(-2.06)	(-2.03)
Top coded	-0.0504	-0.0494	-0.0503	-0.0513	-0.0536	-0.0516	-0.0510	-0.0539
	(-1.30)	(-1.24)	(-1.30)	(-1.33)	(-1.38)	(-1.33)	(-1.32)	(-1.38)
Urban share	0.0216	0.0206	0.0220	0.0210	0.0223	0.0245	0.0231	0.00615
	(0.35)	(0.33)	(0.35)	(0.34)	(0.36)	(0.40)	(0.37)	(0.10)
Urban market access * Cropland		-0.00215						
		(-0.21)						
Rural market access * Cropland		0.00187						
		(0.24)						
Urban market access * Forest			-0.0149					
			(-0.21)					
Rural market access * Forest			0.0187					
			(0.31)					
Urban market access * Small particles				0.0443				
				(1.57)				
Rural market access * Small particles				-0.0278				
				(-1.36)				
Urban market access * Particle thickness					-6.286			
					(-1.63)			
Rural market access * Particle thickness					1.830			
					(0.59)			
Urban market access * Elevation						-0.000357		
						(-0.27)		
Rural market access * Elevation						0.00107		
						(0.87)		
Urban market access * Roughness							0.000373	
							(0.15)	
Rural market access * Roughness							0.000625	
							(0.28)	
Urban market access * Groundwater								0.496*
								(1.90)
Rural market access * Groundwater								-0.501*
								(-1.96)
N	4842	4842	4842	4842	4842	4842	4842	4653
adj. R^2	0.573	0.573	0.573	0.574	0.574	0.574	0.573	0.566

Table: Interaction effects of urban and rural market access with temperature

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Urban market Access	0.170	0.328	-0.290	0.317	-0.471	-0.187	-0.201
	(0.08)	(0.15)	(-0.14)	(0.15)	(-0.22)	(-0.09)	(-0.10)
Rural market Access	0.461	0.331	0.924	0.305	1.407	0.818	0.742
	(0.24)	(0.16)	(0.47)	(0.15)	(0.70)	(0.41)	(0.38)
Initial urban market access	-0.470	-0.449	-0.604	-0.491	-0.505	-0.609	-0.432
	(-0.36)	(-0.34)	(-0.46)	(-0.38)	(-0.39)	(-0.46)	(-0.33)
Initial rural market access	1.465	1.457	1.571	1.484	1.560	1.595	1.398
	(1.15)	(1.15)	(1.24)	(1.18)	(1.23)	(1.24)	(1.10)
Log mean light in 1999	-0.105***	-0.105***	-0.105***	-0.105***	-0.106***	-0.105***	-0.104***
	(-6.83)	(-6.82)	(-6.82)	(-6.78)	(-6.89)	(-6.84)	(-6.79)
Pre-trend	-0.0383**	-0.0383**	-0.0394**	-0.0386**	-0.0399**	-0.0389**	-0.0388**
	(-2.07)	(-2.06)	(-2.12)	(-2.08)	(-2.16)	(-2.09)	(-2.08)
Top coded	-0.0504	-0.0504	-0.0507	-0.0505	-0.0507	-0.0517	-0.0510
	(-1.30)	(-1.30)	(-1.31)	(-1.31)	(-1.31)	(-1.34)	(-1.32)
Urban share	0.0216	0.0219	0.0196	0.0205	0.0227	0.0226	0.0199
	(0.35)	(0.35)	(0.32)	(0.33)	(0.37)	(0.36)	(0.32)
Urban market access * Mean precipitation		0.00584					
		(0.25)					
Rural market access * Mean precipitation		-0.00416					
		(-0.20)					
Urban market access * Precipitation deviation			-0.0388				
			(-0.89)				
Rural market access * Precipitation deviation			0.0354				
			(0.93)				
Urban market access * Precipitation anomaly				0.0614			
				(0.64)			
Rural market access * Precipitation anomaly				-0.0617			
				(-0.65)			
Urban market access * Mean temperature					-0.0771		
					(-0.35)		
Rural market access * Mean temperature					-0.173		
					(-0.84)		
Urban market access * Temperature deviation						1.567	
						(0.30)	
Rural market access * Temperature deviation						-0.324	
						(-0.07)	
Urban market access * Temperature anomaly							4.056
							(1.45)
Rural market access * Temperature anomaly							-1.667
							(-0.70)
N	4842	4842	4842	4842	4842	4842	4842
adj. R^2	0.573	0.573	0.573	0.573	0.574	0.573	0.574