

Measuring economic growth from outer space

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Motivation

- GDP: key measure of economic growth
1. Poorly measured in many LDC's
 - Informal sector
 - Poor government statistical infrastructure
 - Penn World Tables [PWT]: grades countries (PPP)
 - IMF has (0,1) rating: crude and missing countries
 - **WB grades middle and low income on scale of 0–10.**
 - Consistent with IMF where overlap
 - Define countries with very poor data quality.
 2. Not measured in many countries on a regular basis at different sub-national levels
 - Also trans-national regions

Use of night lights data

- History of other proxies
 - Electricity consumption (availability issue)
- Night lights
 - Global coverage on fine spatial scales
 1. Can use light growth combined with GDP growth data to obtain a better estimate of true economic growth for poor data countries
 2. Can use when have no GDP data
 - To predict regional or city level economic growth

Outline of presentation

1. Overview of lights data
2. Model relationships among growth in: lights, true income, & measured income
3. Examine capacity of lights growth to predict measured income growth
4. Use lights data to improve estimates of true economic growth at country level
 - Growth in LCU's
5. Examine facts relevant to certain debates in context of sub-Saharan Africa:
 1. Growth in coastal vs. non-coastal areas
 2. Growth of primate cities vs. hinterland areas
6. Core-periphery in Africa

Night Lights Data

- Source
 - US air force satellites
 - Annual measures from NOAA for 1992–2008
 - Each satellite observes every location on planet between 8:30–10pm local time
 - Use on dark half of lunar cycle; filtered (cloud cover, forest fires, auroral activity); below Arctic Circle
- Measure
 - Intensity as 0–63 annual digital number for every 30-second output pixel (.86 sq. km at equator)
 - Averaged over valid evenings of year (and satellites)
 - Average over pixels (weighted by land area of pixel)
 - Small sub-sample: elasticity of night lights w.r.t. true luminance measures (radiance) ≈ 1.0

Night Lights Data

- Data issues
 - Over-glow, or blooming
 - Top-coding
 - Unlit areas (few low readings under 3)
 - Effective sensor thresholds and scaling factors (“gain”) vary by satellite and ages of satellite
- Issues in usage:
 - Lights reflect evening consumption intensity
 - Public vs. private lights; consumption vs. investment
 - cross-country cultural differences
 - Long term growth versus fluctuations
 - Do lights dim with short term downturns?

Global view

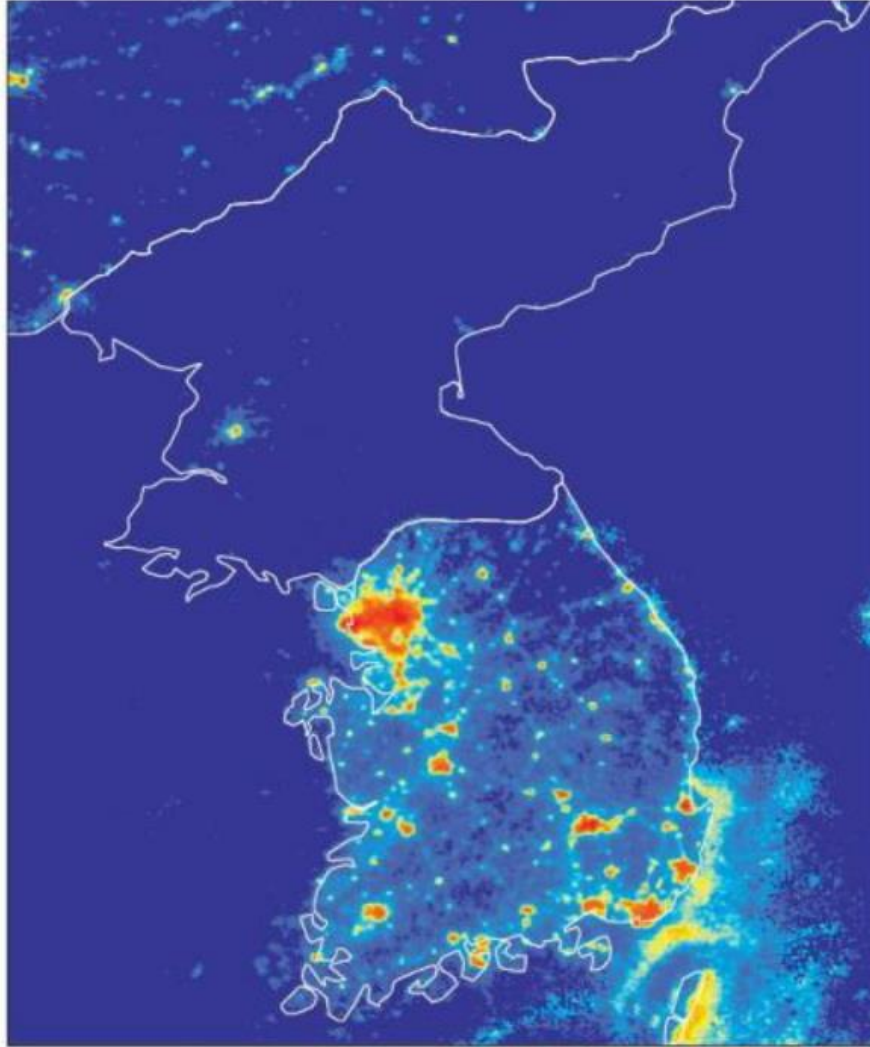


Earth Science Enterprise
Night Lights

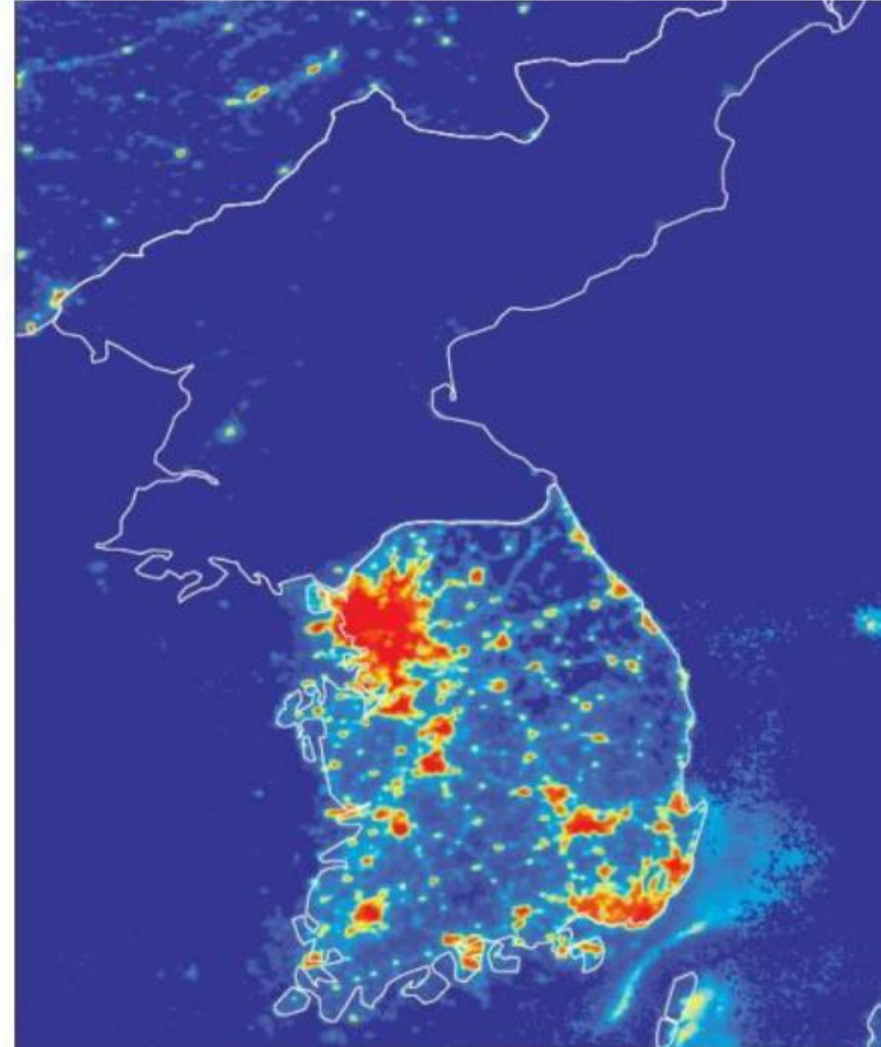
Raw Data

Uncalibrated

% in each cell	Bangla- desh	USA	Canada	Nether- lands	Brazil	Costa Rica	Guate- mala	Mada- gascar	Mozam- bique	M
0	66.72%	71.79%	95.24%	1.00%	94.02%	59.26%	79.23%	99.73%	99.47%	9
1-2	0.64%	0.10%	0.00%	0.00%	0.00%	1.06%	0.24%	0.00%	0.03%	0
3-5	24.48%	9.96%	1.29%	3.45%	2.60%	24.79%	13.84%	0.15%	0.28%	0
6-10	5.27%	8.83%	1.94%	24.04%	1.83%	9.26%	4.17%	0.06%	0.11%	0
11-20	1.69%	4.17%	0.85%	28.83%	0.77%	3.00%	1.46%	0.03%	0.05%	0
21-62	1.13%	4.62%	0.64%	41.10%	0.73%	2.33%	0.95%	0.03%	0.05%	0
63	0.06%	0.53%	0.04%	1.58%	0.06%	0.31%	0.10%	0.00%	0.00%	0
% area unlit	66.94%	67.68%	93.72%	1.05%	94.31%	60.70%	80.42%	99.74%	99.51%	9
avg. DN	2.0108	4.4622	0.7869	23.5244	0.6342	3.1401	1.4059	0.0233	0.0435	0
pop. den. (sq. km)	1080	31	3	469	21	76	105	26	23	0
percent urban	24	79	79	76	81	59	45	27	30	0
GDP p.c. PPP 05	917	37953	31232	32226	8046	8167	3905	892	546	0
GDP p. c. (2000 \$)	344	33582	22657	23208	3760	4084	1693	249	252	0



F-10, 1992

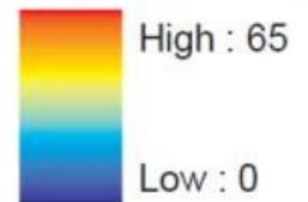


F-16, 2008

- Over time growth
- South vs. north
- Fishing

Figure 2. Korea

Digital Number



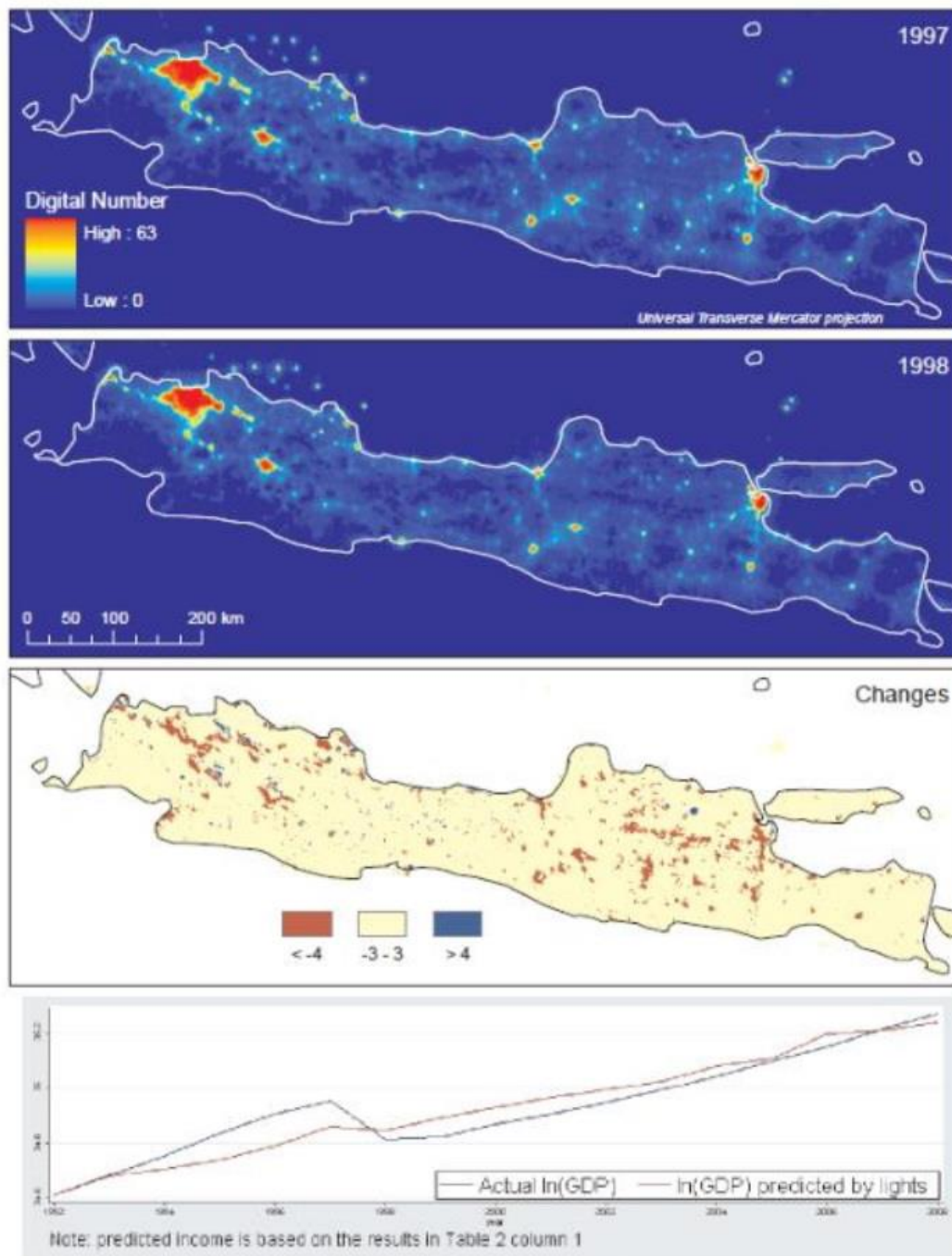
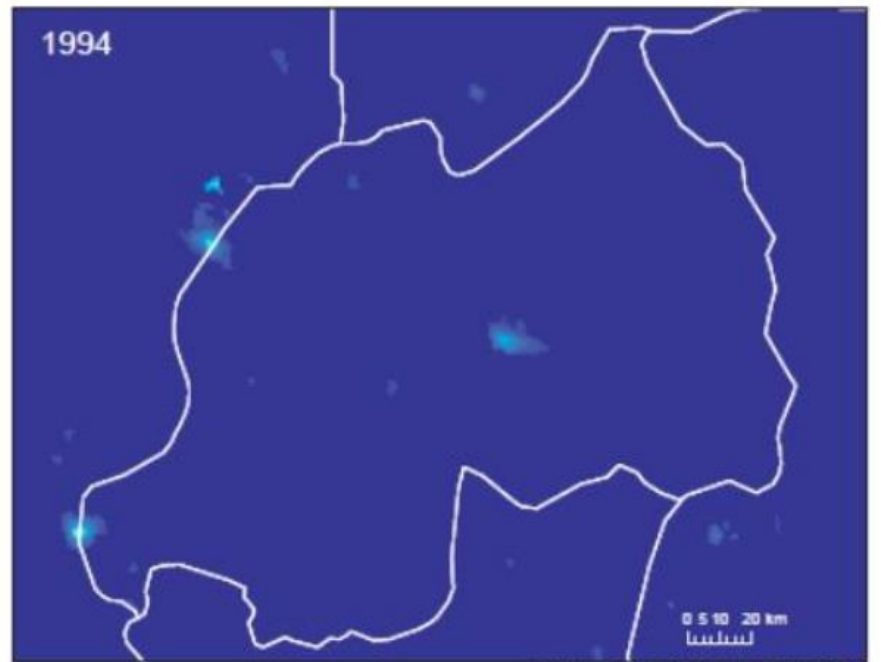
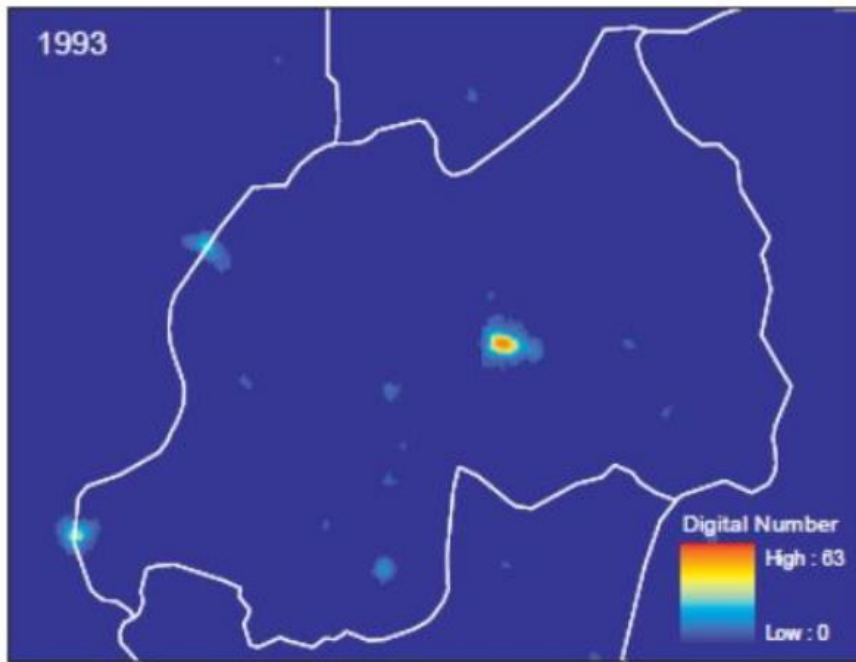


Figure 3: Asian financial crisis: Java, Indonesia



Universal Transverse Mercator projection

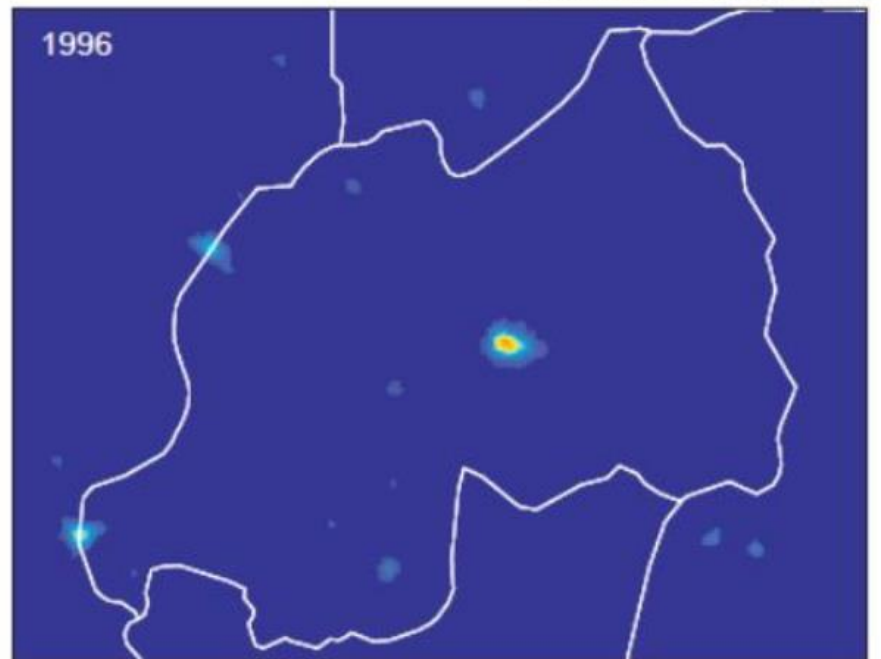
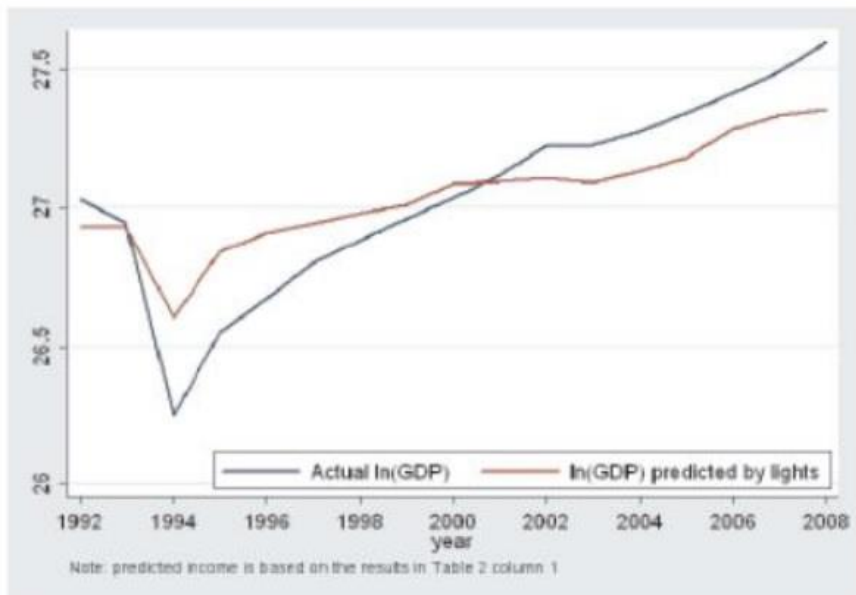
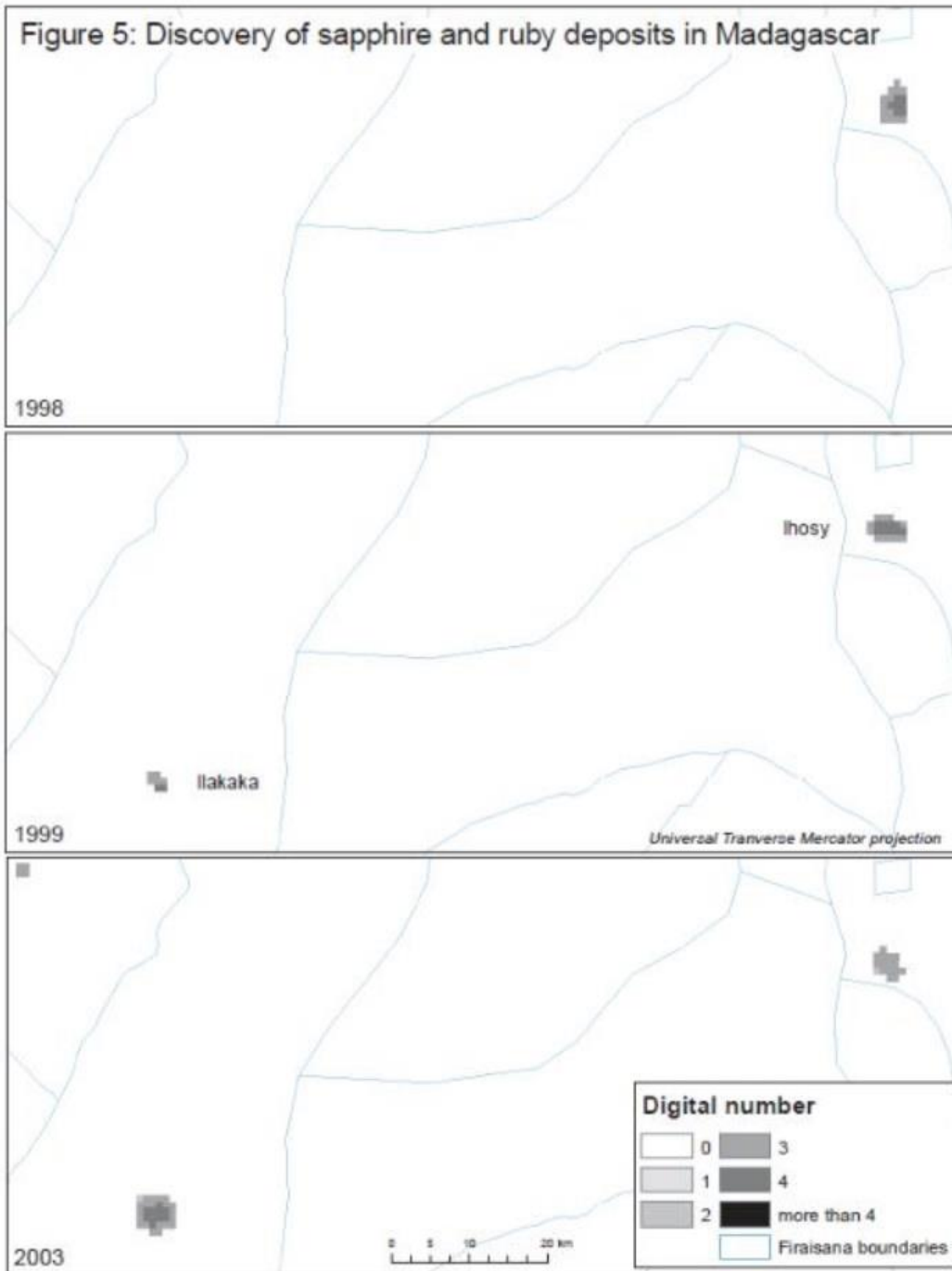


Figure 4: Genocide event: Rwanda

Figure 5: Discovery of sapphire and ruby deposits in Madagascar



Modeling lights as a measure of economic activity

y, σ_y^2 : true GDP growth & its variance

z : **Measured GDP growth**

$$z_j = y_j + \varepsilon_{z,j}$$

σ_z^2 : variance of $\varepsilon_{z,j}$ (measurement error)

Production relationship for growth in lights, x_j :

$$x_j = \beta y_j + \varepsilon_{x,j}$$

σ_x^2 : variance of $\varepsilon_{x,j}$

Key assumption: $Cov(\varepsilon_x, \varepsilon_z) = 0$.

Estimate measured GDP growth as function of lights growth

$$z_j = \hat{\psi} x_j + e_j$$

$\hat{\psi}$ gives biased estimate of $1/\beta$, but equation gives:

Best fit predictor for proxies for growth :

$$\hat{z}_j = \hat{\psi} x_j.$$

Modeling lights as a measure of economic activity

Improve measured growth by obtaining \hat{y} :

$$\hat{y}_j = \lambda z_j + (1 - \lambda) \hat{z}_j$$

Obtain optimal weights λ by minimizing $Var(\hat{y} - y)$:

Yields:
$$\lambda^* = \frac{\sigma_x^2 \sigma_y^2}{\sigma_z^2 (\beta^2 \sigma_y^2 + \sigma_x^2) + \sigma_x^2 \sigma_y^2}$$

Data provide 3 sample moments (to solve $\beta, \sigma_y^2, \sigma_z^2, \sigma_x^2$):

$$\text{var}(z) = \sigma_y^2 + \sigma_z^2 \quad (\text{a})$$

$$\text{var}(x) = \beta^2 \sigma_y^2 + \sigma_x^2 \quad (\text{b})$$

$$\text{cov}(x, z) = \beta \sigma_y^2 \quad (\text{c}) \quad [\text{Note: } \text{cov}(y, x) = \text{cov}(z, x)]$$

4th equation: **ratio "signal" to total variance:**

$$\phi = \frac{\sigma_y^2}{\sigma_y^2 + \sigma_z^2} \Rightarrow \lambda^* = \frac{\phi \text{var}(z) \text{var}(x) - \text{cov}(z, x)^2}{\text{var}(z) \text{var}(x) - \text{cov}(z, x)^2} = \frac{\phi - \rho^2}{1 - \rho^2}$$

Application:

Modeling lights as a measure of economic activity

Look at poorest data low - middle income countries

Assume same lights-economic structure as other low middle income

(same moments: $\text{var}(x) = \beta^2 \sigma_y^2 + \sigma_x^2$ & $\text{cov}(x, z) = \beta \sigma_y^2$)

But different measurement error:

$$\text{var}(z_g) = \sigma_y^2 + \sigma_{z,g}^2 \quad (\text{a})$$

$$\text{var}(z_b) = \sigma_y^2 + \sigma_{z,b}^2 \quad (\text{b})$$

Fifth equation is ratio of signal to total variance

for good data countries, ϕ_g . E.g., $\phi_g = 0.9$

Implies rest of parameters including ϕ_b & $\sigma_{z,b}^2$

Data quality grades from WB: 0-10 scale.

Focus on 30 countries with score of 0-3.

Predicting GDP with lights

- Given geographic, demographic and culture differences, focus on growth of lights for 1992–2008. Three versions:
 1. Country panel to predict annual growth and fluctuations [ratchet effects]
$$\tilde{e}_{jt} = c_j + d_t + e_{jt}$$
 2. Annual fluctuations: add country specific time trend $\kappa_j t$
 3. **Preferred:** Long run growth: long difference for 92/93 to 07/08.

Table 2. Baseline results for the world: 1992-2008; growth in real GDP (constant LCU)

	Just lights			Electricity			Gas f	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ln(GDP)	ln(GDP)	ln(GDP)	ln(GDP)	ln(GDP)	ln(GDP)	ln(GDP)	ln(GDP)
ln(lights/area)	0.275*** [0.031]	0.260*** [0.034]	0.265*** [0.031]	0.286*** [0.034]	0.282*** [0.046]		0.167*** [0.051]	0.283 [0.030]
ln(lights/area) sq.		-0.0060 [0.0060]						
ln(count top-coded + 1)			0.0116* [0.0059]					
ln(unlit)			-0.012 [0.011]					
Spatial Gini				0.179 [0.193]				
ln(KWH)						0.283*** [0.047]	0.201*** [0.041]	
Observations	3014	3014	3014	3014	1853	1853	1853	3014
Countries	188	188	188	188	128	128	128	188
(within) R-sq	0.768	0.769	0.770	0.769	0.757	0.767	0.782	0.768

All specifications include country and year fixed effects

Column (8) excludes regions identified with gas flares.

Robust standard errors in brackets

*** p<0.01, ** p<0.05, * p<0.1

11/2010

Figure 6a. GDP versus lights: overall panel

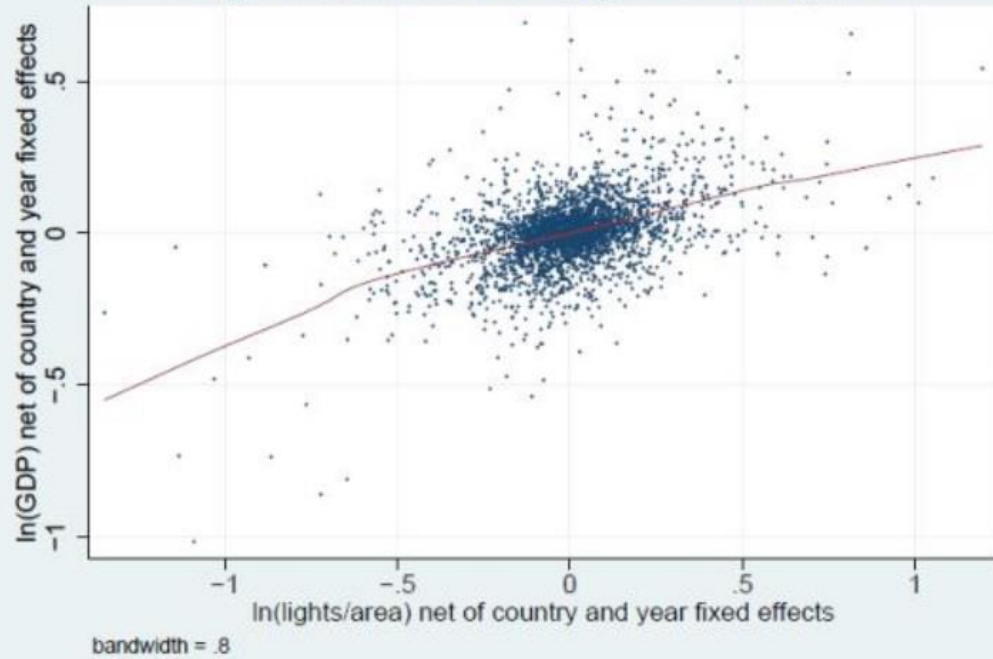


Figure 6b. GDP versus lights: restricted interval panel

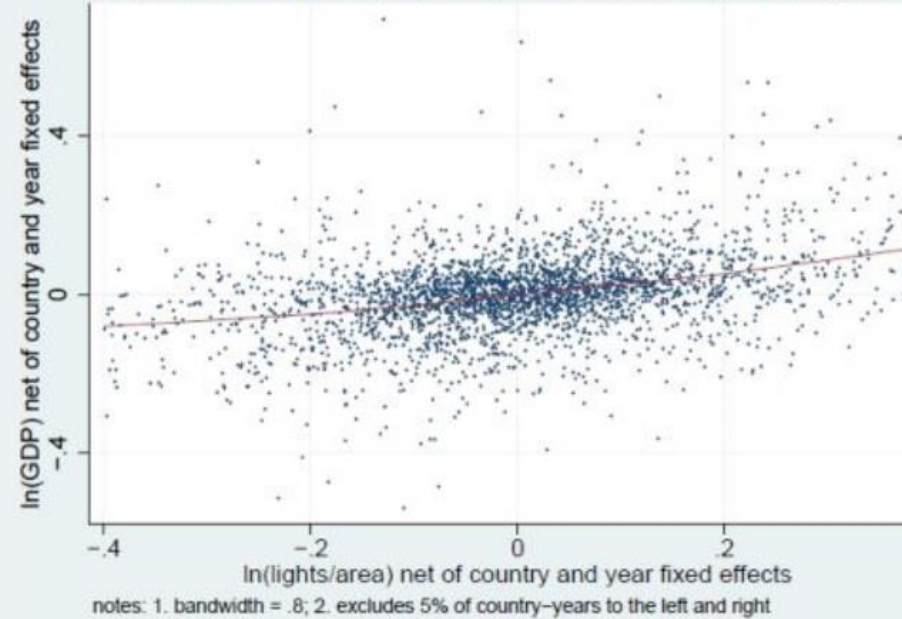


Table 3. Lights up/down, time trend, long difference

	(1)	(2)	(3)	(4)	(5)
	Fixed Effects	Country time trend	Demeaned Plus/Minus	Long difference	Long difference
Indn	0.275*** [0.031]	0.180*** [0.035]		0.317*** [0.037]	0.299*** [0.037]
+Δ ln lights			0.271*** [0.038]		
- Δln lights			-0.280*** [0.055]		
Ln (top-coded + 1)					0.021 [0.015]
Ln (unlit)					-0.0075 [0.023]
Time effects	Yes	Yes	In demean	No	No
Country effects	Yes	Yes	In demean	No	No
Observations	3014	3014	3014	170	170
Countries	188	188	188	170	170
(within) R-sq	0.768	0.905	0.207	0.273	0.282

Robust standard errors in brackets

*** p<0.01, ** p<0.05, * p<0.1

In columns 4 and 5, long differences are formed by averaging the first and last two years of levels data

Figure 6c. GDP versus lights: long differences

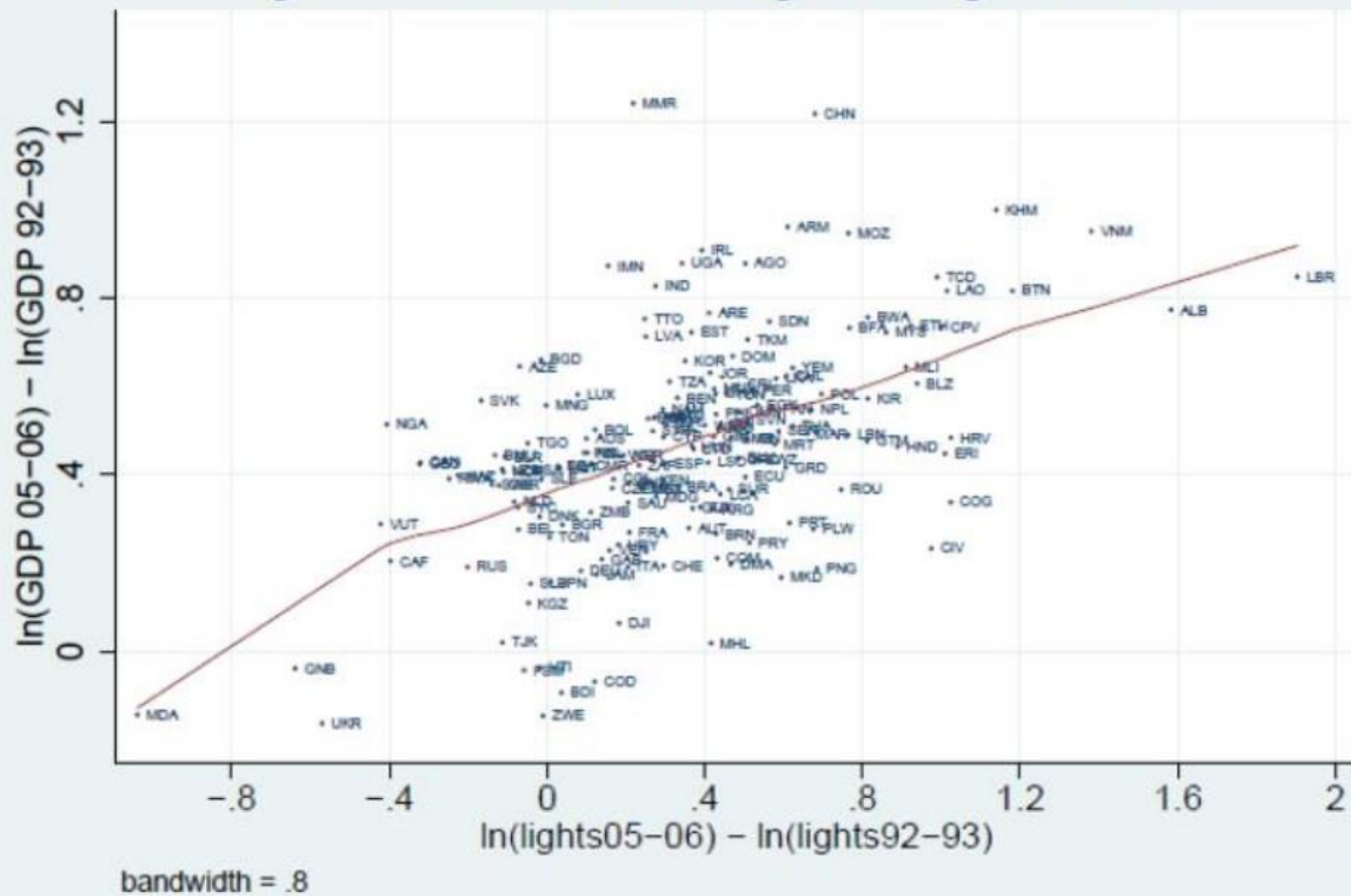


Table 4. Results for rated low-middle income countries; growth in real GDP (LCU units)

	Fixed effects (1)	Country time trend (2)	Long differer (3)
In(lights/area)	0.308*** [0.037]	0.270*** [0.043]	0.329*** [0.046]
Observations	1953	1953	113
Number of isonv10 (Within-country) R-sq	118 0.780	118 0.903	113 0.301
Country fixed effects	Yes	Yes	No
Year fixed effects	Yes	Yes	No
Country time trend	No	Yes	No
Difference for good data countries in ψ (reestimated base not shown)	0.041 [0.063]	-0.013 [0.063]	0.095 [0.092]
Heteroskedasticity: Breusch-Pagan p-value	<0.00005	<0.00005	0.0396
Regression of squared residuals:			
Good data dummy [rating >3]	-0.0055*** [0.0017]	-0.0017* [0.0010]	-0.029 [0.018]
Constant	0.017***	0.0068***	0.068***
Rating >6 (plus, control for rating 4-6)	-0.010***	-0.0044***	-0.041*

Robust standard errors in brackets

*** p<0.01, ** p<0.05, * p<0.1

Improving estimates of true GDP growth

- Long difference formulation 92/92-05/06
- 113 low-middle income WB rated countries, (30 bad)

$$\text{var}(x) = \beta^2 \sigma_y^2 + \sigma_x^2, \quad \text{cov}(x, z) = \beta \sigma_y^2$$

$$\text{var}(z_g) = \sigma_y^2 + \sigma_{z,g}^2, \quad \text{var}(z_b) = \sigma_y^2 + \sigma_{z,b}^2$$

$$\phi_g = \frac{\sigma_y^2}{\sigma_y^2 + \sigma_{z,g}^2}; \quad \text{do for } \phi_g = 1, 0.9, \dots, 0.6$$

Calculate $\hat{\psi}$, \hat{z}_j , λ^* , & $\hat{y}_j = \lambda z_j + (1 - \lambda) \hat{z}_j$

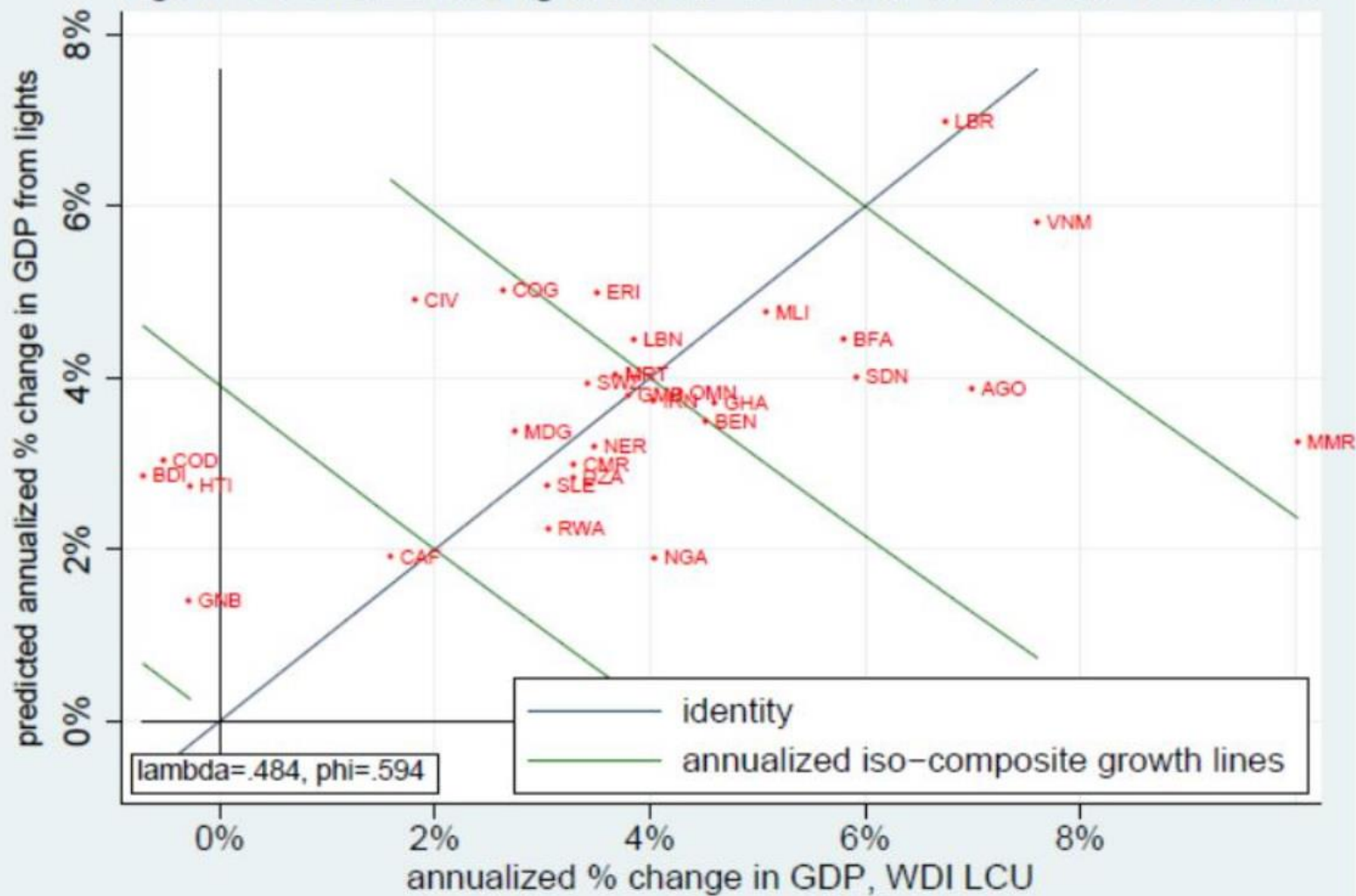
Table 5. Solving the statistical model

Signal to total variance of measured income		Structural effect of true income growth on lights growth	Weight for measured income growth calculation of true growth	
Good data countries:	Bad data countries:		Good data countries:	Bad data countries:
1	0.660	1.032	1.0	0.563
0.9	0.594	1.147	0.852	0.484
0.8	0.528	1.290	0.710	0.407
0.7	0.462	1.474	0.575	0.333
0.6	0.396	1.720	0.449	0.262

Table 6. Average annual growth rates in true income, for bad data countries (1992/93-2005/06)

Country	ISO code	WDI (LCU)	fitted lights	optimal combination of WDI and fitted lights	differenc
Myanmar	MMR	10.02%	3.25%	6.47%	-3
Angola	AGO	6.99%	3.88%	5.37%	-1
Nigeria	NGA	4.04%	1.90%	2.93%	-1
Sudan	SDN	5.92%	4.01%	4.93%	-0
Vietnam	VNM	7.60%	5.82%	6.67%	-0
Burkina Faso	BFA	5.80%	4.46%	5.10%	-0
Benin	BEN	4.52%	3.50%	3.99%	-0
Ghana	GHA	4.60%	3.71%	4.14%	-0
Rwanda	RWA	3.06%	2.24%	2.63%	-0
Algeria	DZA	3.29%	2.84%	3.06%	-0
Oman	OMN	4.28%	3.84%	4.05%	-0
Mali	MLI	5.08%	4.77%	4.92%	-0
Sierra Leone	SLE	3.04%	2.75%	2.89%	-0
Cameroon	CMR	3.29%	2.99%	3.14%	-0
Iran, Islamic Rep.	IRN	4.03%	3.74%	3.88%	-0
Niger	NER	3.48%	3.20%	3.34%	-0
Gambia, The	GMB	3.80%	3.80%	3.80%	0
Liberia	LBR	6.75%	6.99%	6.87%	0
Central African Republic	CAF	1.59%	1.92%	1.76%	0
Mauritania	MRT	3.68%	4.04%	3.86%	0
Swaziland	SWZ	3.42%	3.94%	3.69%	0
Lebanon	LBN	3.85%	4.45%	4.16%	0
Madagascar	MDG	2.74%	3.38%	3.07%	0
Eritrea	ERI	3.51%	4.99%	4.27%	0
Guinea-Bissau	GNB	-0.29%	1.41%	0.58%	0
Congo, Rep.	COG	2.63%	5.02%	3.86%	1
Haiti	HTI	-0.28%	2.74%	1.27%	1
Côte d'Ivoire	CIV	1.82%	4.91%	3.40%	1
Congo, Dem. Rep.	COD	-0.52%	3.04%	1.30%	1
Burundi	BDI	-0.71%	2.86%	1.12%	1

Figure 7: Growth in fitted lights vs. WDI for WBDQ<3.5 countries 1992–2006



Application: Lights when no GDP numbers exist: sub & trans national

- Sub-Saharan Africa (not South Africa):
 1. If you're not on the coast, you're toast
(Gallup Sachs, & Mellinger, 1999)
Huge petro price rise in 2000's; land-locked countries
 2. Primate vs. hinterland growth (Ades & Glaeser 1995; Davis & Henderson, 2004)
Favoritism of primate (usually national capital regions)

Process

- Divide Sub-Saharan Africa into two types of areas in each case.
- Sum digital number for all pixels in each type of area in each year.
- Compare difference in log sums, over time for each area.
 - Relative comparison allows for area and time fixed effects

Facts and fantasies

- Coast (& navigable waterways) 100km buffer as in Mellinger, Gallup & Sachs
 - World trade volume up 250% in time span, real petroleum prices up
 - Landlocked & not great highways. Who gains from increased trade?
- Inland lights grew by .133 log points more.
 - Using $\hat{\psi}$ from Table 4, implies inland areas grew by 1/3 percent point more per year
 - Growth (not level) differences
 - **Why?**

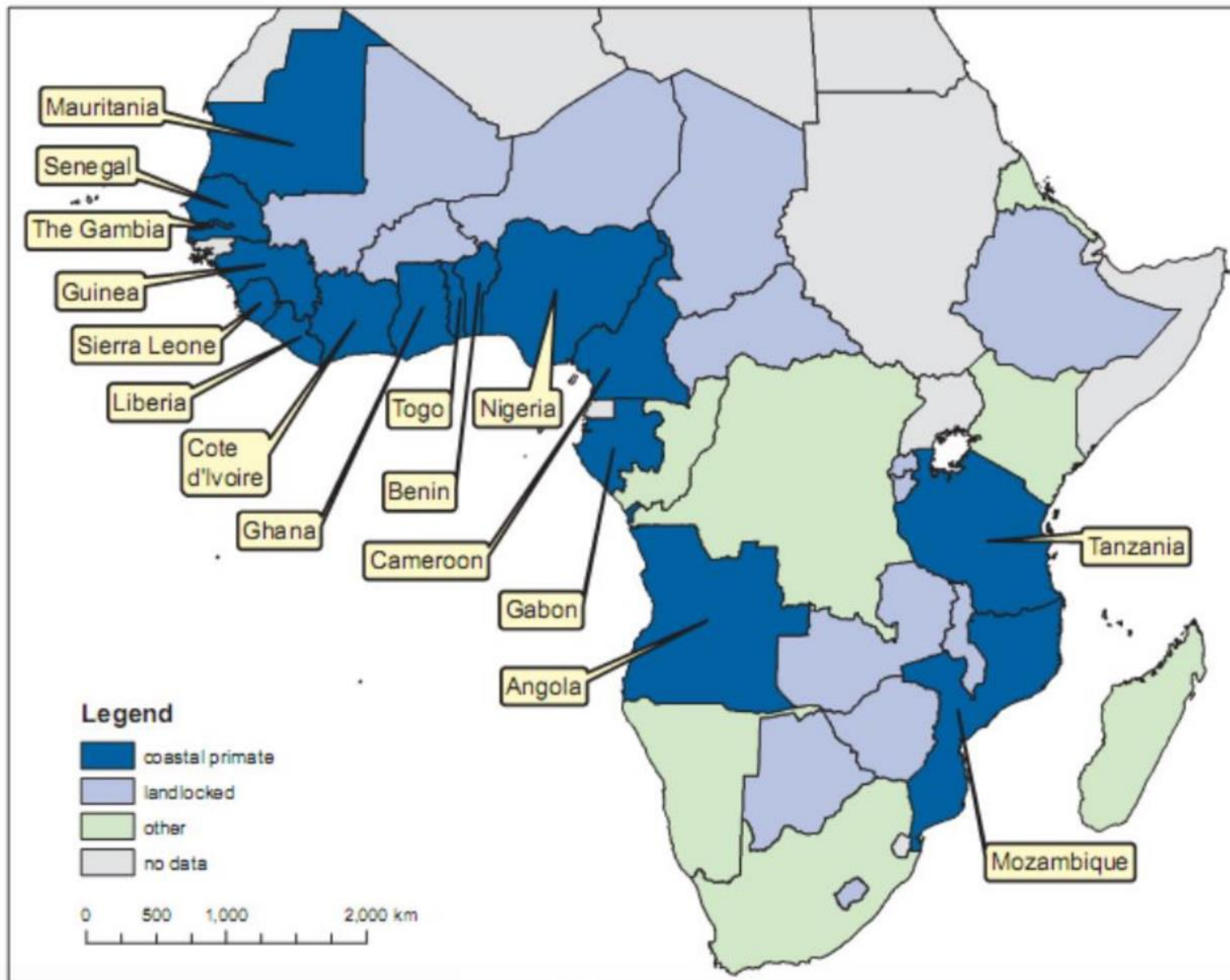
Facts and fantasies

- Primate cities vs. hinterland areas
 - Primate: Polygon envelope of contiguously lit areas (with largest population in country)
 - **No difference in relative growth**
 - If primate still favored, big waste!

Core-periphery in Africa

Adam Storeygard

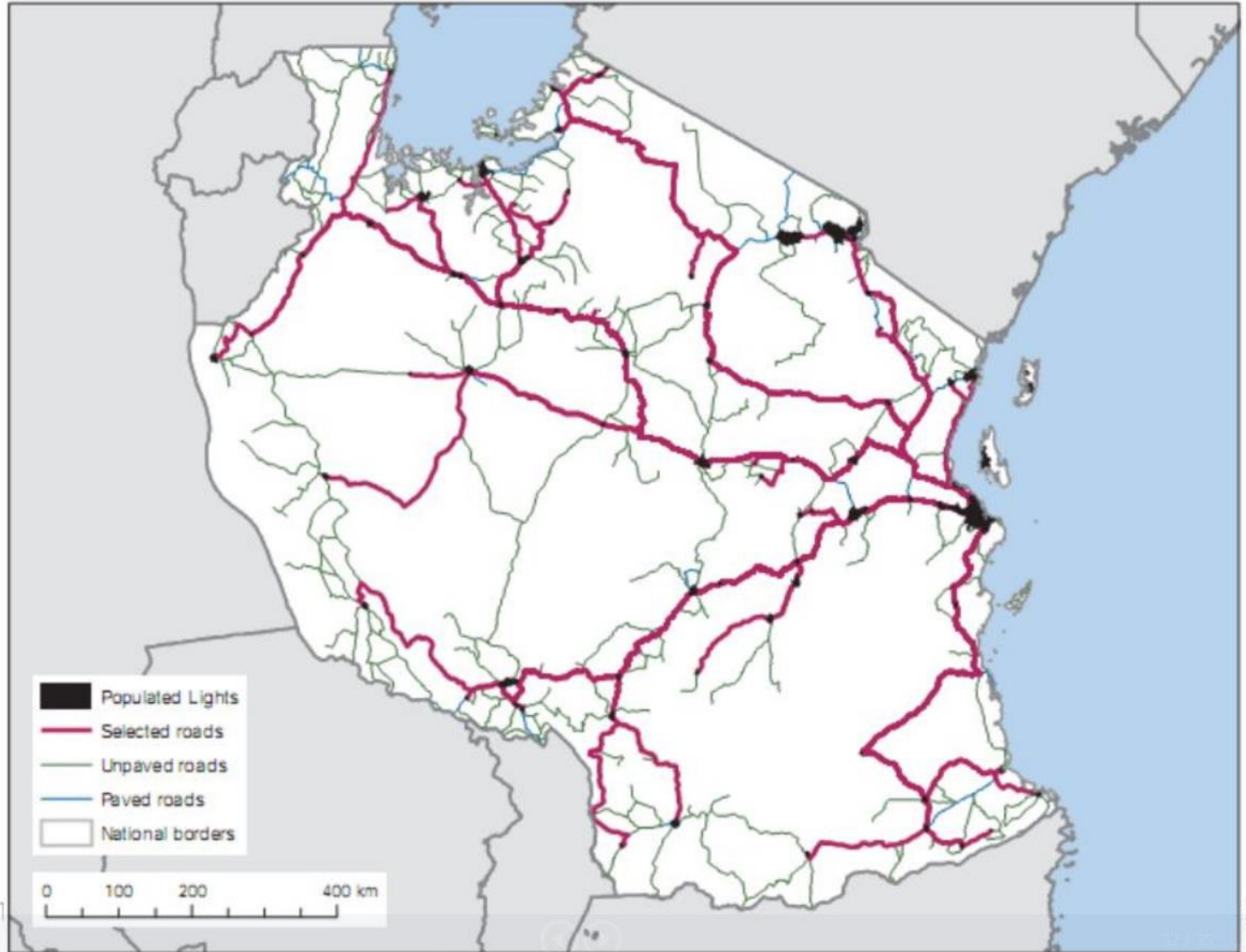
- General question: Are cities further from the coastal primate city of a country disadvantaged by distance?
 - If so, to what extent?
- Various models, e.g. NEG core-periphery
- Here ask: if unit transport costs rise, to what extent do cities further from the coast lose relatively more, compared to those nearer to the coast?
 - Experiment: huge rise in oil prices in 2000's



Data

- From censuses identify cities over 20,000
- Use lights for defined polygon areas of cities to measure economic activity over time (1992–2008)
- Use WB roads data (given year usually from near 2005) and find best link along routes to interior cities.
 - Some information on paving and quality

Tanzania



Empirical Specification

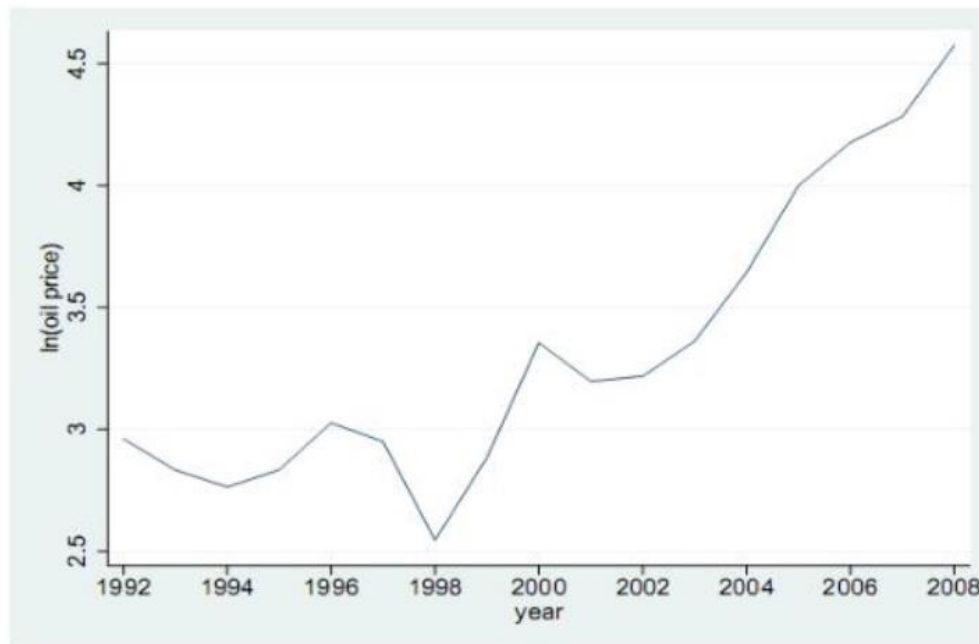
$$\ln x_{ict} = Bp_t * d_i + \alpha_{np}t + \alpha_p t + \lambda_i + \mu_{ct} + \varepsilon_{ict}$$

i : city. c : country. t : time

α : time trend coefficient: non-primate vs. primate

p_t : world price of oil

d_i : road distance from city i to primate city
in 1000's of kms.



Results

	OLS ln(DN+4)	OLS ln(DN+4)
$p*d$	-0.00386*** (0.00146)	
$lnp * ln(d+1)$		-0.0545*** (0.0181)
<i>Time trend : n.p.</i>	0.134*** (.0198)	0.157*** (0.021)
<i>Time tend: diff. p</i>	-.0337*** (.00923)	-0.0598** (0.0121)
N (cities)	4913 [289]	4913 [289]

- Oil price goes from \$20 to \$90.
- For city that is 1s.d. further away from primate city (450 kms.), lights are 12% less [if move to maximum distance: 60+% less
- Using an elasticity of 0.3 for lights to income growth, that is 3.3% less in income for 1 s.d. of distance

Conclusions

- Lights' growth is a reasonable predictor of income growth
 - Empirical growth analysis no longer need be tied to availability of (high quality) GDP data
- Can be combined with official numbers to get an improved estimate of true income growth – **for poor data countries**
- Can be used at sub & trans-national level to evaluate patterns of income change/growth