Is climate change driving urbanization in Africa?

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Motivation

- Last 50 years: declining moisture in Sub-Saharan Africa, a substantial part of which is already dry
  - Future climate change: uncertain for Africa
    - Warming almost certain, drying possible
- **Can the negative effects on agriculture from climate deterioration be mitigated by enhanced urbanization?**
  - Role of climate in driving urbanization
    - Depends on degree to which region is ready for urbanization
- Figure 1-3 on declining **moisture**
  - Moisture is rainfall divided by potential evapotranspiration (PET) from UNEP (1992) .
    - Values below one indicate a deficit: “less precipitation than would be evaporated at prevailing temperatures”

Figure 1 . Historical levels of moisture

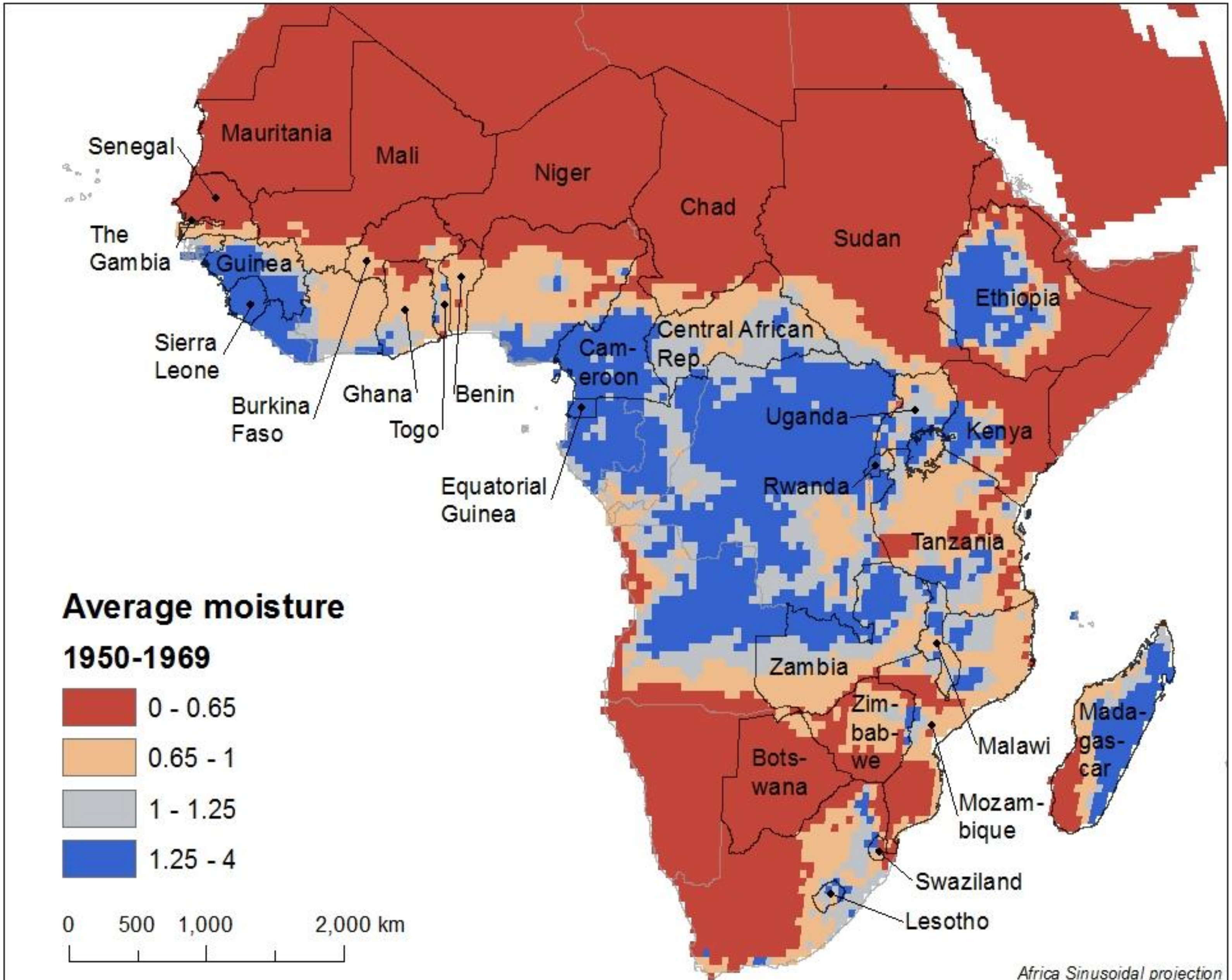


Figure 2. Drying out in Africa since 1950

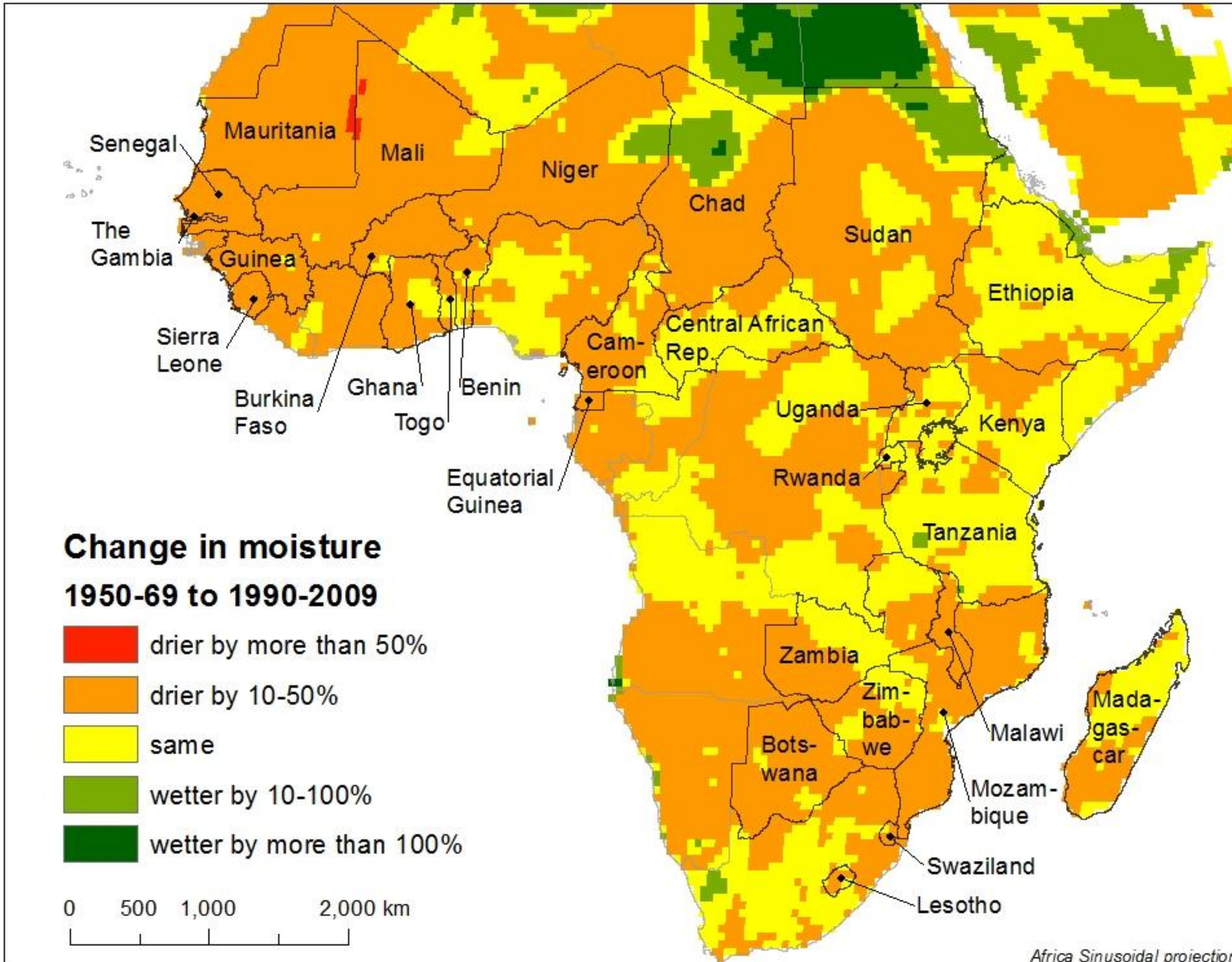
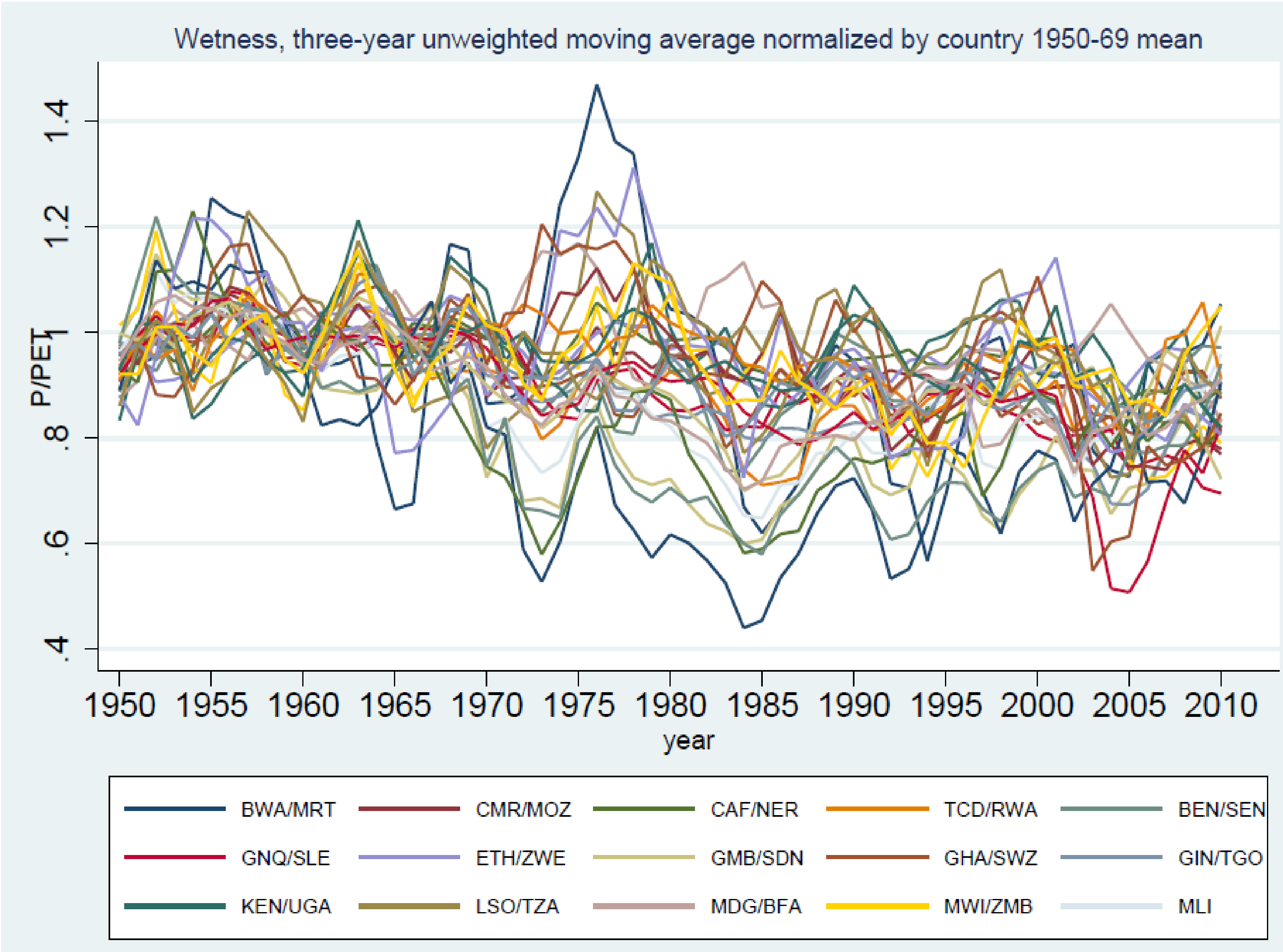


Figure 3. Year by year declining moisture in African sample



Moisture/wetness is precipitation divided by potential evapotranspiration (PET) from UNEP (1992). PET is calculated using the Thornthwaite (1948) method (Willmott et al, 1985)

Three questions

- What are the local effects of reduced moisture on:
  1) Local, district level urbanization
  2) Local city incomes (night lights)
  3) Occupational choice within rural sector
- Two sources of heterogeneity
  - Propensity of local cities to manufacture tradable goods
    - Degree to which local towns not entirely dependent on agriculture
  - Baseline aridity/moisture level

Summary of results

1. **Has declining moisture driven people out of agriculture and into (nearby) towns within a district or province?**

- Yes for districts that are already industrialized; no otherwise (75+ % of time)
  - 1 s.d. decline in (annualized) growth in moisture increases growth rate of urbanization within districts by
    - 50% of mean growth rate for districts most likely to be manufacturers
    - For arid countries: 65% of mean for manufacturing districts

Summary of results

2. How does rural moisture decline affect TOTAL income of nearby cities and towns?

- If local towns are likely to have tradable manufactures
  - **Reduced moisture increases total city income**, despite decline in per capita income
  - Elasticity of the income growth measure, night lights growth, with respect to moisture is - 0.09 to -0.17 for places most likely to have manufacturing.
- If towns are just agricultural service centers (75% of time)
  - Zero or modest effect in **opposite** direction
    - Moisture decline reduces local incomes of farmers who then reduce spending in cities and lower incomes there

Summary of results

3. Do decreases in moisture affect occupational choice in the rural sector?

- Three categories: work on farm, work off farm, not work
- Women are more likely to report not working (instead of working on the farm)
- Men more likely to report working off-farm

Some literature

- **Climate as push factor in African urbanization (Barrios et al)**
  - National urbanization every 5 years
  - We use within-country variation
    - Most migration in Africa is local (Jonsson, 2010)
  - We consider each country's intercensal periods
- Microdata migration literature (Henry, Schoumaker, Beauchemin, 2004 and Beauchemin and Bocquier, 2004)
  - Recollected first moves of rural people in West Africa
    - Relocate to urban areas , relocate to other rural areas (or out of country)
- Sub-Saharan Africa (SSA) is different:
  - Urbanization without growth? (Fay and Opal, 2000)
    - Drivers of urbanization: Jedwab (2012), Gollin et al (2013), Henderson Roberts and Storeygard (2013)
  - Lack of technological progress in African agriculture: limited adaptability
- Climate change literature

Conceptual framework

- Local district as small open economy, with rural & urban populations
  - Perfect mobility between rural and urban; none across districts
- Rural produces agriculture for export
- Town/city has two sectors (potentially)
  - Manufactures (m): tradable on national markets
  - "Services" (s): local (non-traded)
- Districts "small open economies"
  - Then if increased agricultural productivity, that may induce people to stay on farm as returns to farming rise
    - Vs. Caselli & Coleman (2001): Closed economy & preferences such that agricultural productivity growth lowers farm population
      - **Here identify effects from within country variation in growth in moisture**

Sectors

- **Urban**: linear city with commuting costs (Duranton and Puga, 2004)
  - Technology:
    - Services: Constant returns, wage $w = bp_S$
    - Manufacturing: increasing returns, $w = cL_M^{\varepsilon}$
    - Urban full employment net of commuting costs:

$$L = L_S + L_M = N_U(1 - tN_U)$$

- Rural

Per worker income: $p_A f(N_A, R)$

Population, N_A ($f_1 < 0$)

Rainfall, R ($f_2 > 0$)

Framework continued

- **District equilibrium,** 7 equations for 7 unknowns:

  $N_A, N_U, p_S, L_M, L_S, y, w$

  no rural-urban arbitrage: $y = p_A f(N_A, R) = p_s b(1 - tN_U)$

  no urban sector arbitrage: $w = cL_M^{\varepsilon} = bp_S$

  district full employment: $N_U + N_A = N$

  urban full employment: $L_S + L_M = N_U(1 - tN_U)$

  services market clearing: $bL_S = N\ D(y,\ p_a,\ p_s)$

- Key comparative statics for empirical work: effect of moisture changes on:
  - Urban population: dN_U / dR
  - Total urban income (city lights data): $d(yN_U) / dR$

Comparative statics in general

Population: $\dfrac{dN_U}{dR} = \dfrac{f_2}{f} \quad \dfrac{L_M + \varepsilon L_S(\eta_y + \eta_{p_S})}{Z} < 0,$ if $L_M + \varepsilon L_S \eta_{p_S} > 0$

(at least modest manufacturing)

$\dfrac{f_2}{f}$: effect of moisture on ag. production (more in arid places)

Stability requires: $Z(L_M + \varepsilon L_S \eta_{p_S})^{-1} < 0$

$$L_M + \varepsilon L_S \eta_{p_S} > 0 \longrightarrow Z < 0 \longrightarrow \frac{dN_U}{dR} < 0$$

City income: $d(yN_U)/dR < 0$

- draw people out of city

$dy / dR > 0$ (no dynamic effects modelled)

Comparative statics when cities just serve agriculture ($L_M \to 0$)

- Tend to have opposing effects, compared to when industry present
- Results influenced by price and income elasticities of demand for services

If $\eta_y + \eta_{p_S} \geq 0$, then $\dfrac{dN_U}{dR} \geq 0$; otherwise ambiguous

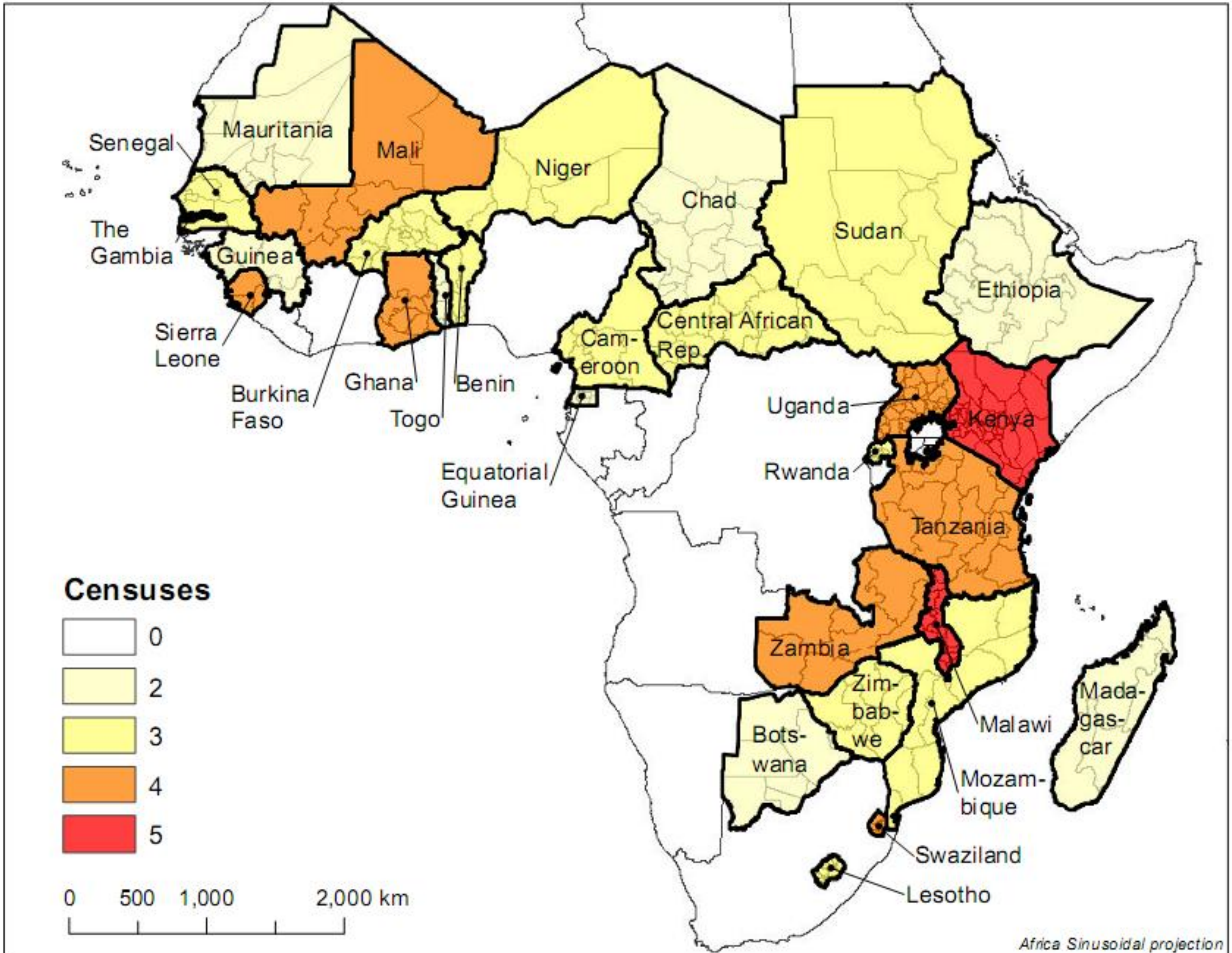
Unless $\eta_y + \eta_{p_S} << 0$, $\dfrac{d(yN_U)}{dR} > 0$

Summary

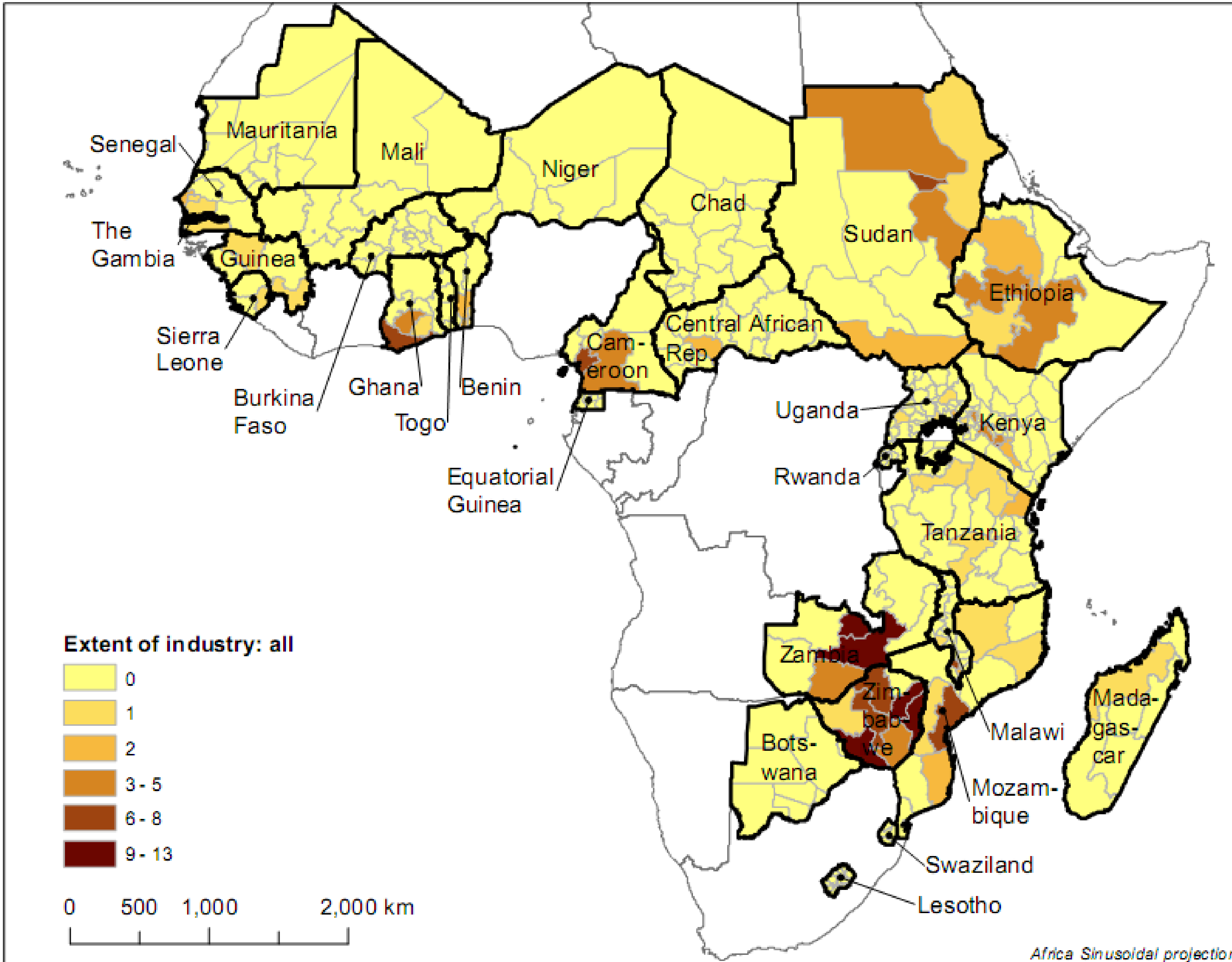
- **Proposition 1.** If the district city has a traded good manufacturing sector (that is not too small), **a decline in moisture** will lead to (1) an increase in urban population and (2) an increase in *total* city income.
  - **Bigger effect when moisture influences ag. productivity more**
- **Proposition 2**. If the district city has no/"tiny" manufacturing sector, (a) effect on city population is ambiguous/small and (b) in general, if moisture declines, city income declines
  - Little population effect and loss of overall productivity.
- **"Dynamics": When do local towns manufacture?**
  - improved technology (education)
  - increased price of manufactures (national or world markets)
  - transport cost reductions

Question 1 on urbanization: Data

- Temperature and precipitation from U Delaware
  - Annual 0.5 degree grid interpolated from station data
- Urban/rural population by district:
  - 89 censuses (libraries/archives + online)
  - Different years for different countries
    - Unbalanced panel -> "First" difference data between censuses and annualize instead of district fixed effects
- Propensity to manufacture: Oxford Atlas (1965)
  - Location of industrial activity by industry (26) and city
  - 3 categories: all, "modern" (exclude agri. processing), "key" (upstream)
    - responses $\frac{dN_U}{dR}, \frac{d(yN_U)}{dR}$ increase as $L_M / L_S \uparrow$



Mauritania
Senegal
Mali
Niger
Chad
Sudan
The Gambia
Guinea
Ethiopia
Sierra Leone
Central African Rep
Cam-eroon
Burkina Faso
Ghana
Benin
Togo
Uganda
Kenya
Equatorial Guinea
Rwanda
Tanzania
Censuses
0
2
3
4
5
Zambia
Zim-bab-we
Malawi
Mada-gas-car
Bots-wana
Mozam-bique
Swaziland
Lesotho
0 500 1,000 2,000 km
Africa Sinusoidal projection



Mauritania
Mali
Niger
Chad
Sudan
Senegal
The Gambia
Guinea
Sierra Leone
Burkina Faso
Ghana
Togo
Benin
Cam-eroon
Central African Rep
Ethiopia
Uganda
Kenya
Rwanda
Equatorial Guinea
Tanzania
Zambia
Zim-bab-we
Bots-wana
Malawi
Mada-gas-car
Mozam-bique
Swaziland
Lesotho
Extent of industry: all
0
1
2
3 - 5
6 - 8
9 - 13
0 500 1,000 2,000 km
Africa Sinusoidal projection

Question 1: Sample

- SSA countries between 1960 and 2010, requiring
  - 2 or more reliable population censuses (not Nigeria)
  - Relatively constant internal boundaries with migration permitted (not South Africa)
  - Have sub-national data on urban & rural populations
  - Could get data (vs. Paris library closure)
- 29 countries, 366 districts, 741 district-year differences (trimmed 717)
    - Trim highest and lowest growth in moisture and in share urban
  - Good coverage in dry places (e.g. Sahel)
  - No data available: DR Congo, Cote d'Ivoire, Angola, Somalia

Panel specification

$$u_{ijt} = \beta_0 m_{ijt,smooth} + \beta_1 m_{ijt,smooth} X_i + a_{jt} + \varepsilon_{ijt}$$

where for district *i* in country *j* in year *t* :

- u_{ijt}: **annualized growth in urban pop share,** $t\text{-}L_{jt}$ to t
- L_{jt} is # years between prior census and year t

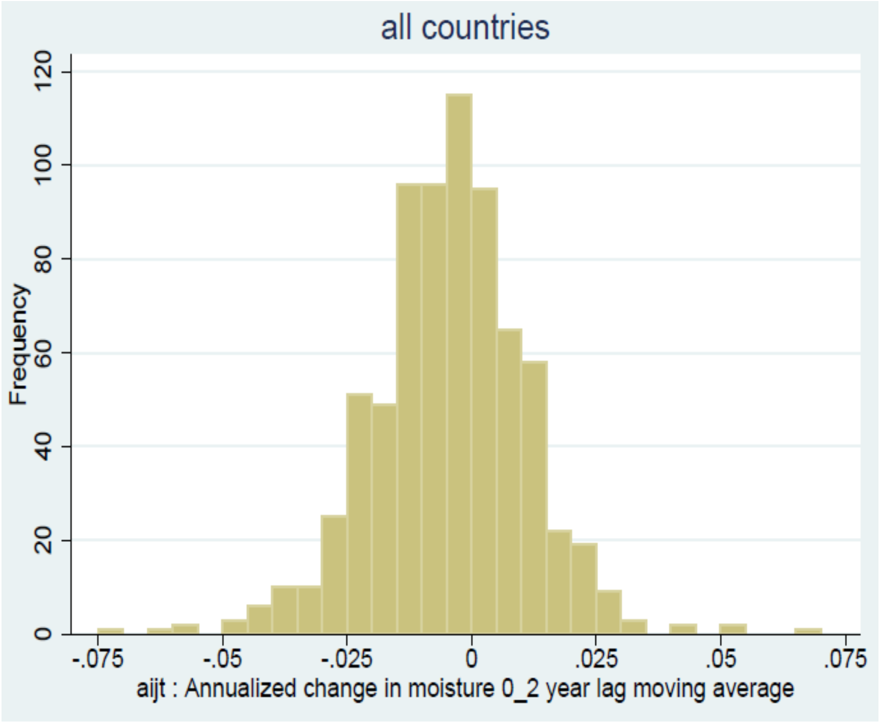
$$m_{ijt,smooth} = [\ln M_{ij,t,smooth} - \ln M_{ij,t-L_{jt},smooth}] / L_{jt}$$

- $M_{ijt,smooth}$ is average moisture from *t-2* to *t*
  - Smoothing reduces noise in data
- X_i is for heterogeneity (baseline manu. & moisture)
- a_{jt} is a country*year fixed effect
  - Controls for country trends (& changing definition of urban)
- **ID: within country-year variation in growth rates**

Identification Issues

- Sufficient within-country variation in moisture growth?
- Moisture declines randomized or not?
  - No incidental simple correlation with other factors except distance to coast
    - Includes initial climate, initial urbanization, degree of industrialization. “Balance in data”
  - Control for distance of coast & initial level of urbanization (convergence) [last has issues]
- Defining arid regions [moisture < 1]
  - Little within-country heterogeneity
  - Tend to use country-level threshold

Distribution of growth in moisture



Raw data

With country-year
fixed effects
removed

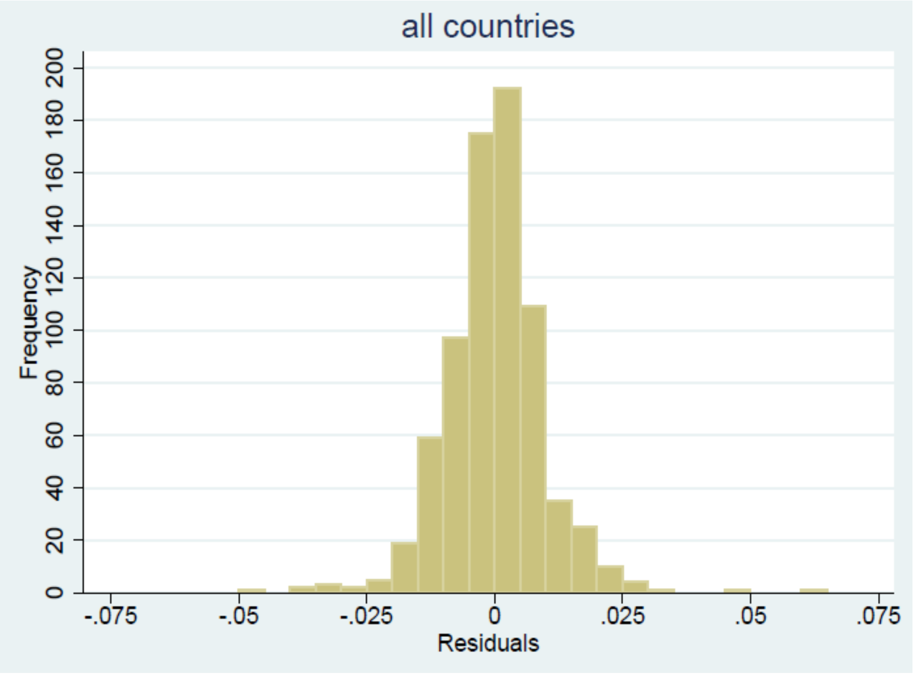


Table 2 Effect of moisture change on urbanization: Heterogeneity by likelihood of industry

	(1)	(2)	(3)	(4)
Δmoisture	-0.0768	-0.622*	**-1.017*** **	**-1.136*** **
	(0.181)	(0.357)	**(0.331)**	**(0.334)**
Δmoisture*1(No key industries)		0.620*		
		(0.353)		
Δmoisture*increasing degree of agriculture			**0.125*** **	
(8 - #modern industries)			**(0.0426)**	
Δmoisture*increasing degree of agriculture				**0.0867*** **
(13 - #all industries)				**(0.0266)**
1(No key industries)		0.00249		
		(0.00519)		
8 - #modern industries			-0.000352	
			(0.00131)	
13 - #all industries				0.000217
				(0.000740)
Initial share urban	-0.0499***	-0.0509***	-0.0554***	-0.0524***
	(0.00514)	(0.00715)	(0.00887)	(0.00817)
ln(dist. to coast)	0.00121	0.00130	0.00135	0.00129
	(0.00173)	(0.00174)	(0.00171)	(0.00173)
R-squared	0.387	0.391	0.391	0.391

Notes: Each column is a separate regression with 717 observations for 365 districts. The dependent variable is growth in the urbanization rate. 8 and 13 are the maximum number of modern and total industries, respectively, in any given district. Robust standard errors, clustered by district, are in parentheses. All specifications include country*year fixed effects. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table 2a: Varying smoothing, trimming and controls in Table 2, column 4

	Base	Trimming				Drop controls	Smoothing		
	1	2	3	5	6	7	10	11	12
Δmoisture	**-1.136*** **	-1.467**	-0.820**	-1.120***	-1.052***	-0.836**	-0.479*	-1.028***	-1.131*
	(0.334)	(0.576)	(0.318)	(0.329)	(0.272)	(0.370)	(0.281)	(0.356)	(0.582)
Δmoisture* (13	**0.0867*** **	0.123***	0.0740***	0.0898***	0.0796***	0.0659**	0.0357	0.0725**	0.0825*
# all industries)	**(0.0266)**	(0.0456)	(0.0250)	(0.0257)	(0.0222)	(0.0293)	(0.0233)	(0.0296)	(0.0470)
13 - #all industries	0.000217	-0.00192	-0.000132	0.000238	0.000561	0.00368***	0.000104	8.61e-05	0.000208
	(0.000740)	(0.00125)	(0.000787)	(0.000750)	(0.000711)	(0.000427)	(0.000731)	(0.000756)	(0.000794)
Initial share urban	-0.0524***	-0.0782***	-0.0569***	-0.0523***	-0.0479***		-0.0505***	-0.0513***	-0.0515***
	(0.00817)	(0.0153)	(0.00917)	(0.00794)	(0.00678)		(0.00798)	(0.00809)	(0.00818)
ln(dist. to coast)	0.00129	0.00190	0.00207	0.00123	0.000824		0.00125	0.00139	0.00127
	(0.00173)	(0.00171)	(0.00168)	(0.00171)	(0.00149)		(0.00173)	(0.00174)	(0.00175)
Observations	717	741	733	709	677	717	717	717	717
R-squared	0.391	0.365	0.378	0.388	0.410	0.360	0.388	0.389	0.389
Trimmed	24	0	8	32	64	24	24	24	24
Smoothing	0-2	0-2	0-2	0-2	0-2	0-2	0-1	0-3	0-4
districts	359	369	366	356	350	359	359	359	359

Initial non-urbanization as proxy for lack of industry	Δmoisture	Δmoisture* I(not in top 20% initial urban)	I(not in top 20% initial urban)	Ln (dist to coast)
	-0.154 (0.199)	0.0701 (0.198)	-0.0226*** (0.00238)	0.00240* ((0.0015)

Table 3. Effect of moisture change on urbanization: heterogeneity by degree of aridity

	(1)	(2)	(3)
Δmoisture	-0.409***	-0.295	-0.622**
	(0.136)	(0.193)	(0.241)
Δmoisture*1(country moisture>1)	0.473		
	(0.304)		
Δmoisture*1(district moisture>0.75)		0.334	
		(0.258)	
Δmoisture*District moisture 1950-69			0.545**
			(0.265)
1(district moisture>0.75)		0.0188	
		(0.0202)	
District moisture 1950-69			0.0230
			(0.0187)
R-squared	0.391	0.392	0.399

Notes: Each column is a separate regression with 717 observations for 365 districts. The dependent variable is growth in the urbanization rate. Controls not reported are **initial urbanization and ln(distance to the coast) and then each interacted with the moisture variable relevant to each column**. Robust standard errors, clustered by district, are in parentheses. All specifications include country*year fixed effects. *** p<0.01, ** p<0.05, * p<0.1

Table 4. Effect of moisture change on urbanization: heterogeneity by industrialization and aridity

	(1)	(2)	(3)	(4)	(5)
industry measure	Key	Modern	All	All	All
aridity measure	1(country moisture>1)			1(dist. moisture>0.75)	dist. moisture
Δmoisture	-0.876***	-1.187***	-1.213***	**-1.929*** **	**-2.509*** **
	(0.194)	(0.361)	(0.367)	**(0.460)**	**(0.880)**
Δmoisture*1(No key industries)	0.574***				
	(0.188)				
Δmoisture*(8 - #modern industries)		0.107**			
		(0.0473)			
Δmoisture*(13 - #all industries)			0.0683**	**0.132*** **	**0.153** **
			(0.0294)	**(0.0391)**	**(0.0716)**
Δmoisture*1(country moisture>1)	0.341	0.0789	-0.0803		
	(0.673)	(0.643)	(0.661)		
Δmoisture*1(district moisture>0.75)				**1.021** **	
				(0.478)	
Δmoisture*District moisture 1950-69					**1.395**
					(0.955)
Δ moisture*industry variable*moisture variable	0.0739	0.0444	0.0400	**-0.0527**	**-0.0670**
	(0.642)	(0.0800)	(0.0509)	**(0.0464)**	**(0.0778)**
R-squared	0.395	0.395	0.395	0.398	0.405

Notes: Each column is a separate regression with 717 observations for 359 districts. The dependent variable is growth in the urbanization rate. 8 and 13 are the maximum number of modern and total industries, respectively, in any given district. Robust standard errors, clustered by district, are in parentheses. **All specifications include country*year fixed effects and controls for initial urbanization, ln (distance to the coast) and the relevant district industry variable. There is then any district moisture variable and each of initial urbanization, ln(distance to coast) and district industry variable interacted with the relevant moisture (district or country) variable.** *** p<0.01, ** p<0.05, * p<0.1

Other factors

- **Further potential forms of heterogeneity**
  - Irrigation “potential”
  - Soil suitability
  - Soil water retention capacity
  - Within year variation in rainfall (Gini)
  - Noisier signal
    - Stand. error of prediction: $\sqrt{\sum_{s=t-L_j}^{t} (\hat{W}_{ijs,\text{smooth}3} - W_{ijs,\text{smooth}3})^2 / (L_j - 2)}$
    - Intercensal change in standard deviation
- **No stable heterogeneity found**

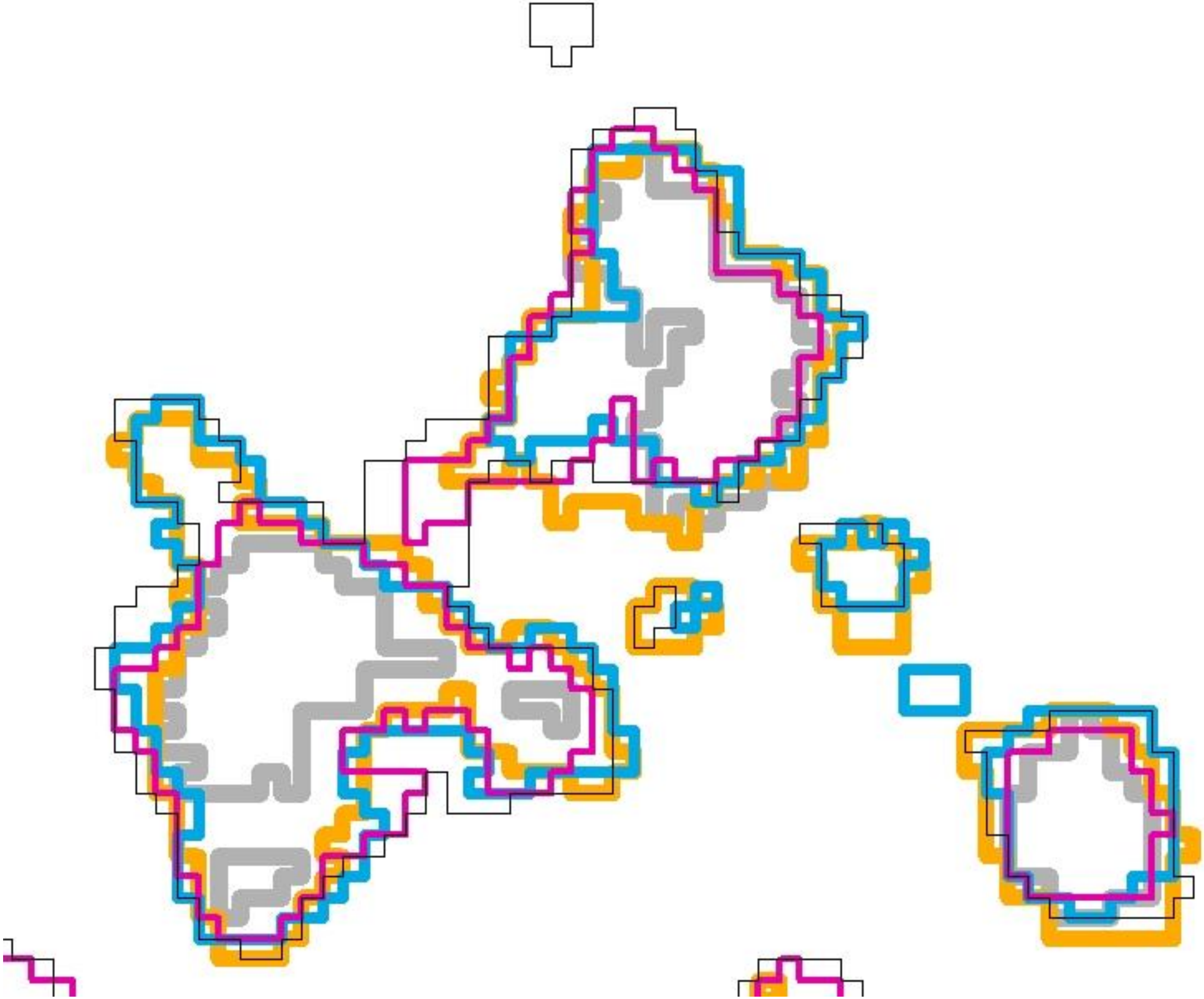
Question 2: Local city income growth

- Less rainfall decreases farm income. Two situations
- If city has manufacturing
  - City competes with agriculture for labor
  - **Rainfall down, city income up** (people move to city)
- If no manufacturing
  - Little migration response
  - **Rainfall down, city income down** (generally)
- Annual data
  - looking at immediate responses
  - Limited evidence of lags
  - Timing very different than Question 1

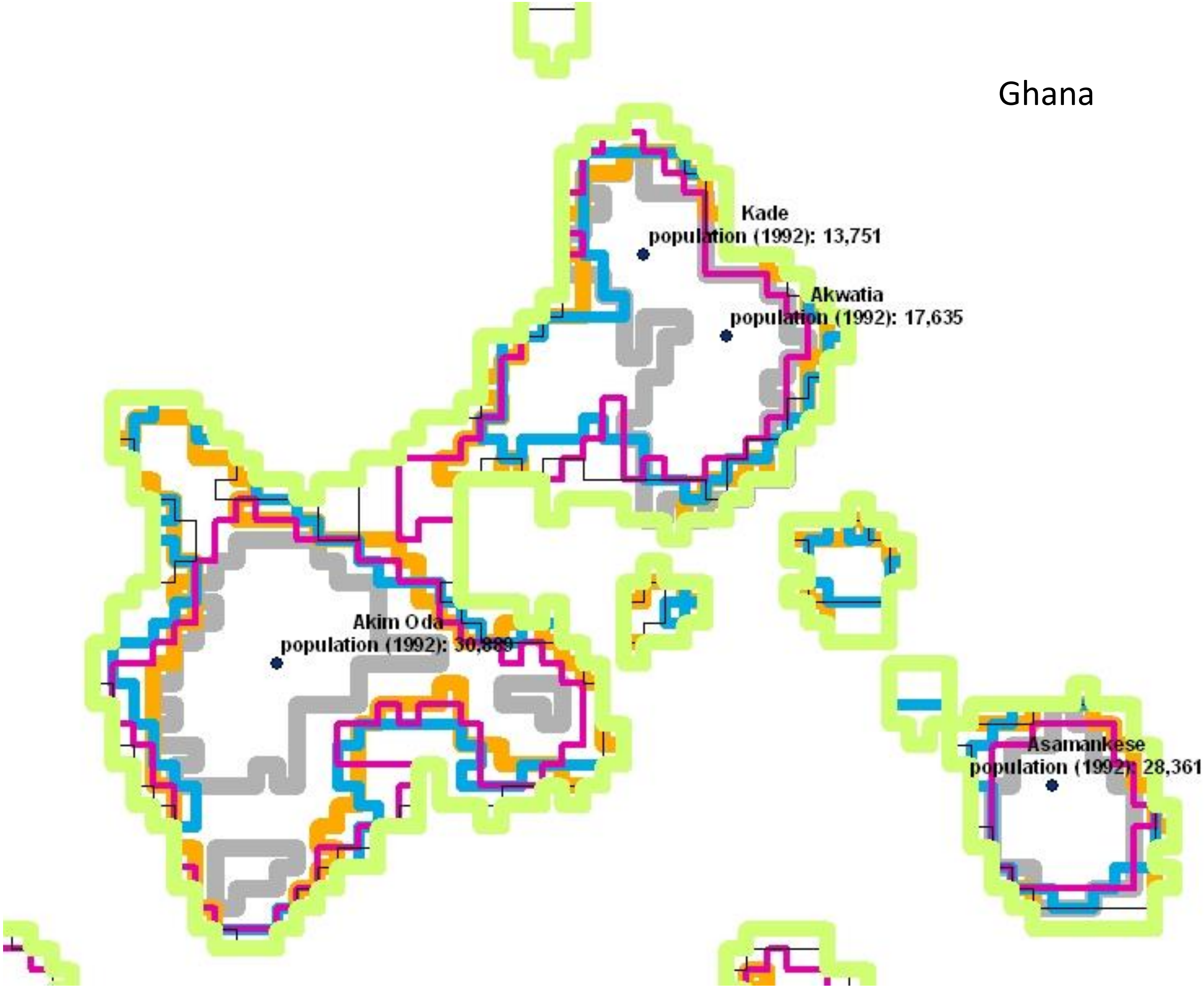
Question 2: Data

- Outcome measure: growth in lights emitted to space at night
  - Proxy for growth in economic activity (Henderson, Storeygard and Weil, 2012)
  - Measures of economic activity are not available for cities
  - Lights and weather data exist for every year 1992 to 2008
- Analysis unit: blobs of contiguous ever-lit 1-km pixels
  - Union of overlapping lights across years (outer envelope)
  - Rain catchment area: 30km radius around city light
- Sample: 1158 cities in 42 countries in Sub-Saharan Africa
  - Must have city population
  - Omit areas with gas flare problem
  - Omit cities where lights spill over national borders
- Rainfall (fine geographic scale): satellite and station data
  - Africa Rainfall Climatology Version 2

City lights: outer envelope across years

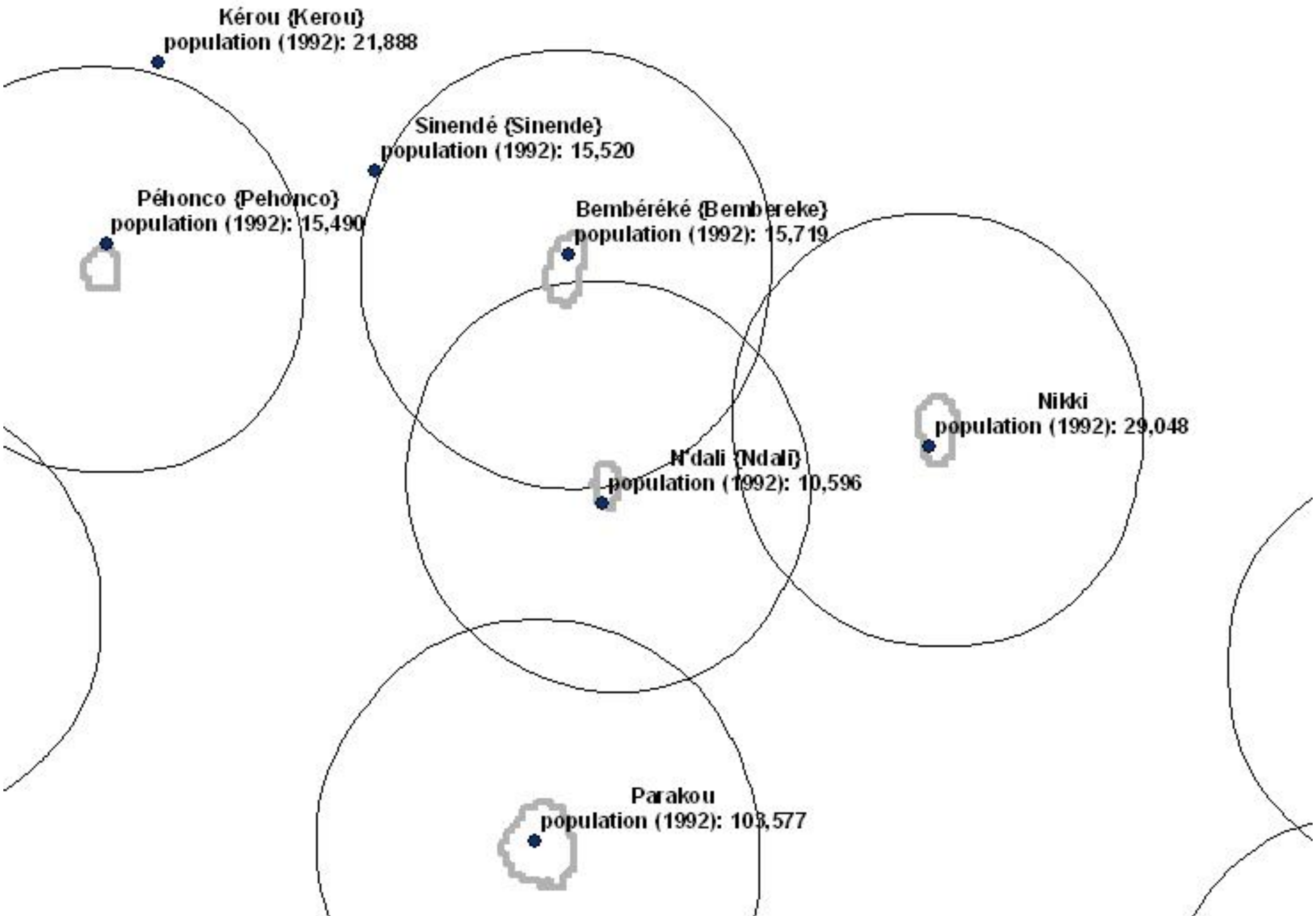


Adding population



Rain "catchments"

Benin



Empirical specification

$$\Delta \ln\left(light_{it}\right) = \beta_0 \Delta \ln(R_{it}) + \beta_1 X_i \Delta \ln(R_{it}) + \phi_i + \lambda_t + \varepsilon_{it}$$

where:

- i indexes city and t year,
- $light_{it}$ is lights summed over pixels in city i, in year t (with 0->5)
- R_{it} is average rainfall within 30 km of city i,
- X_i is heterogeneity (baseline moisture and manufacturing propensity)
- φ_i and λ_t are city (time trend) and year fixed effects
- ε_{it} are errors clustered at city level (serial correlation)

- Notion: city on its own growth path: climate variability moves it up and down around that path

Basic results

- Specification involves **annual fluctuations** in rainfall – implied migration responses may be limited. Nevertheless
  - For arid countries with cities likely to have manufacturing base, elasticity of city lights with respect to moisture is - 0.09 to -0.17
  - For arid countries which are more farm based, net effect is zero or small positive

Table 5. Growth in lights: manufacturing heterogeneity

	(1)	(2)	(3)	(4)
Δln(rain)	-0.0095	-0.074***	-0.170***	-0.138***
	(0.012)	(0.015)	(0.066)	(0.052)
Δln(rain)*1(agri/GDP>30%)		0.102***		
		(0.022)		
Δln(rain)*(9-#mod. ind.)			0.018**	
			(0.008)	
Δln(rain)*(13 - #all ind.)				0.0102**
				(0.004)

Table 6. Growth in lights: double heterogeneity (no city aridity measure)

	(1)	(2)	(3)	(4)
Δln(rain)	-0.0069	-0.091***	-0.169**	-0.139**
	(0.012)	(0.015)	(0.080)	(0.060)
Δln(rain)*1(agri./GDP>30%)		0.133***		
		(0.022)		
Δln(rain)*(9 - #modern ind.)			0.018**	
			(0.009)	
Δln(rain)*(13 - #all industries)				0.0105**
				(0.005)
Δln(rain)*1(country moist.>1)	-0.015	0.098*	-0.0051	0.0054
	(0.040)	(0.058)	(0.126)	(0.115)
Δln(r)*1(moist>1)*1(ag>30)		-0.180**		
		(0.078)		
Δln(r)*1(moist>1)*(9-#mod)			-0.00104	
			(0.016)	
Δln(r)*1(moist>1)*(13-#all)				-0.0016
				(0.010)

Other factors

- No evidence of leads or little of lags
  - Lags only for country level defined manufatcuring
- Robust to controlling for hydroelectricity

Question 3: Reactions *within* the rural sector

- Rainfall will affect returns to farming & the decision to
  - not work (whatever that may mean)
  - work on farm
  - work in non-farm activities in rural sector
- Issues
  - Selection: who remains in the rural sector?
  - General equilibrium effects: lower returns to farming mean less income and returns to all activities locally.
  - Definitions of work

Change in non-agricultural activity in rural sector in SSA

Share of agriculture in total rural employment (males in DHS)

Country	Beginning year share		Ending year share		Source
Malawi	**0.91**	**('87)**	**0.66**	**('08)**	**IPUMS**
Niger	**0.87**	**('92)**	**0.57**	**('06)**	**DHS**
Benin	**0.85**	**('96)**	**0.72**	**('06)**	**DHS**
Senegal	**0.75**	**('92)**	**0.54**	**('05)**	**DHS**
Kenya	0.57	('93)	0.46	('09)	DHS
South Africa	0.28	('96)	0.16	('07)	IPUMS
Cameroon	0.79	('91)	0.75	('04)	DHS
Chad	0.92	('96)	0.90	('04)	DHS
Burkina-Faso	0.94	('93)	0.90	('03)	DHS

Data

- 43 Demographic and Health surveys for 18 countries (37 surveys in 17 countries for men)
  - 1996-2011
  - Rural only
  - Must have 12-month recall work info and GPS data
- Create “superclusters” (3939 for females; 3751 for males)
  - Cluster sampling
  - No panel
  - Location of villages randomized (disclosure issue)
  - Next sample year: different clusters, but nearby
  - Start with initial clusters and group next ones according to which initial cluster they are closest to.

Specification

- $y_{icjt} = \alpha_0 x_{icjt} + d_{jt} + \beta W_{cjt} + f_c + e_{icjt}$ (4)

individual *i* in supercluster *c*, in country *j* and year *t*

  - y_{icjt} is a multinomial choice (not work, work in agriculture, work in non-agriculture)
  - x_{icjt} is individual characteristics: age (and age squared) and education dummies;
  - W_{cjt} is average wetness over the three previous years;
  - f_c is a super-cluster fixed effect for OLS; district fixed effect in probit/logit). (not a panel per se.)
  - d_{jt} is a **country-year fixed effect**; and
  - e_{icjt} is an error term clustered at the super-cluster level.

Table 8: Occupational choice (LPM)

	Female			Male		
	(1)	(2)	(3)	(4)	(5)	(6)
	not working	other	agri	not working	other	agri
moisture	-0.055***	-0.004	**0.059*** **	-0.012	-0.055**	**0.067*** **
	(0.018)	(0.015)	(0.022)	(0.013)	(0.022)	(0.025)
obs	312,769	312,769	312,769	100,788	100,788	100,788
provinces	148	148	148	121	121	121
super-clusters	3939	3939	3939	3751	3751	3751

Each specification includes country*year fixed effects, age, age^2 and 3 education dummies
Errors clustered by supercluster *** p<0.01, ** p<0.05, * p<0.1

Multinomial probit gives slightly bigger effects for women, none for men
Suggests with moisture declines:

- Females leave farm work for other activities
- Males leave farm work and take off-farm work (less stable results)

Conclusion

- Declines in moisture
  - Encourage city population growth in manufacturing districts (enhanced in arid countries)
    - Not in non-industrialized districts
  - Raise total urban income in industrialized districts
    - Lower total urban income in more agricultural settings, or no effect
  - Reduce rural participation in farm labor
    - Females to household
    - Males to off-farm work