The Real Effects of Climate Change in Poor Countries: Evidence from the Permanent Shrinking of Lake Chad

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Motivation

- **Climate change (IPCC):** "*change in the state of the climate that can be identified [...] by* changes in the mean *and/or the variability of its properties and that persists for an extended period, typically* decades" [classical period for averaging climate vars = 30 yrs]

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- Empirical studies of the causal effects of climate change focus on climate shocks, which by construction are not permanent.

  $\rightarrow$ How can we measure the causal effects of permanent changes?

- Simulation-based studies estimate the effects of future climate change, not climate change that has been happening since 1950s.

  $\rightarrow$ How can we estimate non-simulated effects of climate change?

Motivation

- To study the local & aggregate effects of climate change, we need:
  - A permanent change in climate-driven geographical conditions.
  - The change must be slow enough (over several decades).
  - The change must be locally exogenous.
  - Localized economic data during (1960s-onwards) as well as before the change (1950s). Particularly difficult for the poorest countries that will be most affected by future climate change (e.g., in Africa).
  - A model that helps us rationalize the effects.
  - The model must be able to generate clear policy prescriptions.

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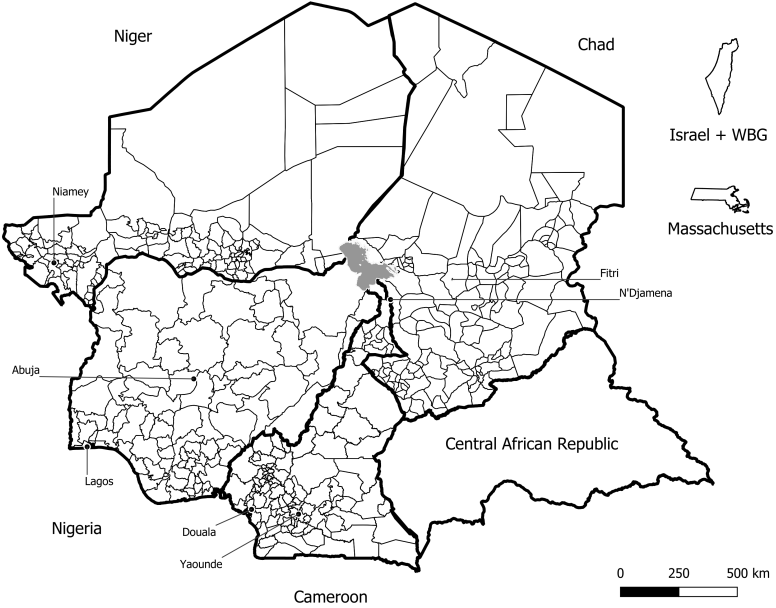
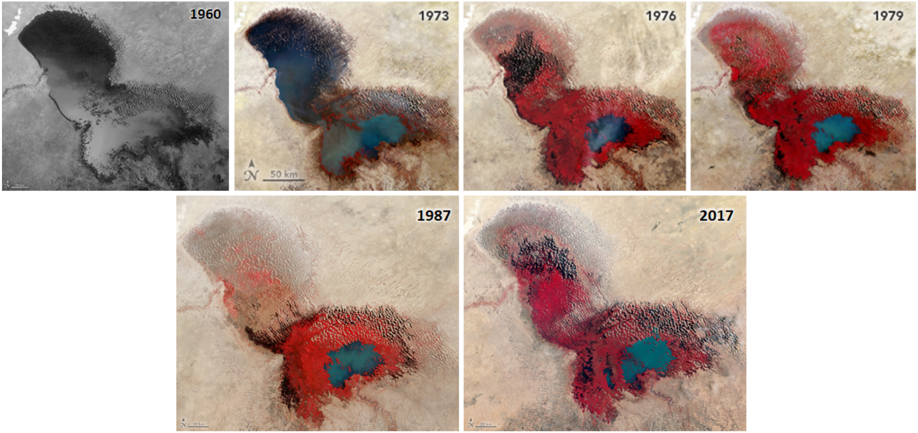
  - The model must be able to generate clear policy prescriptions.

$\Rightarrow$ **Study (unexpected) permanent shrinkage of major lake post-1965.**



Focus on shrinkage of Lake Chad (11th largest in world; size of Israel + WBG or Massachussets) in four countries (275 million; 25% of sub-Saharan Africa).

Lake Chad Started Drying c. 1965, 90% Water Loss c. 1990



Will explain later why the shock was locally exogenous.

Source: Reproduced from Hansen and Przyborski (2017) – NASA Earth Observatory

What We Find

Research question

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Effects a priori ambiguous. If less water, also get more land.

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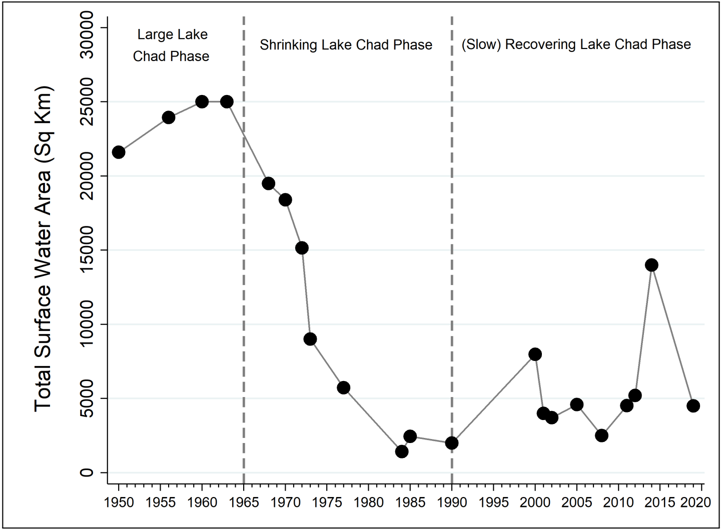
Reduced-form results

- Cameroon, Chad, Niger & Nigeria: Context of data scarcity.
- Novel data subdistrict level 1940s-2010s: total & city pop.
- Much slower pop. growth around lake (water effect dominates). Less negative effects on city pop. $\rightarrow$ "refugee" urbanization.

Simulation-based results

- Quantitative Spatial Model with multiple locations.
- Quantify aggregate welfare loss and study effects of policies.

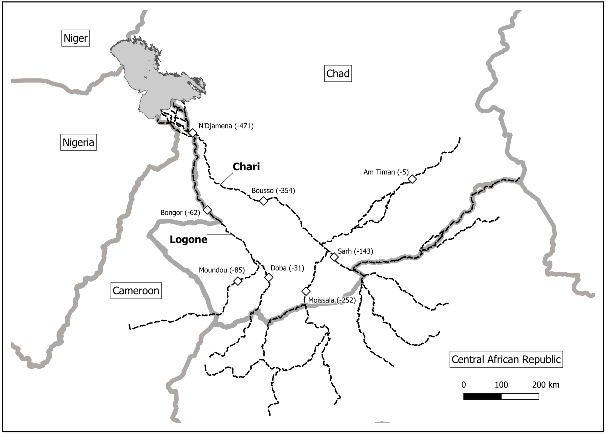
Lake Chad's Evolution (Shock c. 1965)



Loss = 23,000 sq km (c. size of Israel+WBG, El Salvador or Massachusetts).

Lake Chad is a Sink Fed by Rain 800-1000 Km Away

- Almost all of lake's water comes from the Logone-Chari river complex.
- Logone & Chari originate in Central African Rep.'s mountainous areas.*
- From 1960s: Less rain in Africa → all locations impacted *but* lakes (sinks) more impacted.
- Niger: More exogenous. Cameroon+Chad: Ctrls for access to rivers.



* Due to declining discharge rates of rivers in Central African Rep.: Moissala, Sarh (average 1965-1980 vs. average 1950-1964; m^3/s), not rivers in Cameroon or Chad

Many Possible Mechanisms

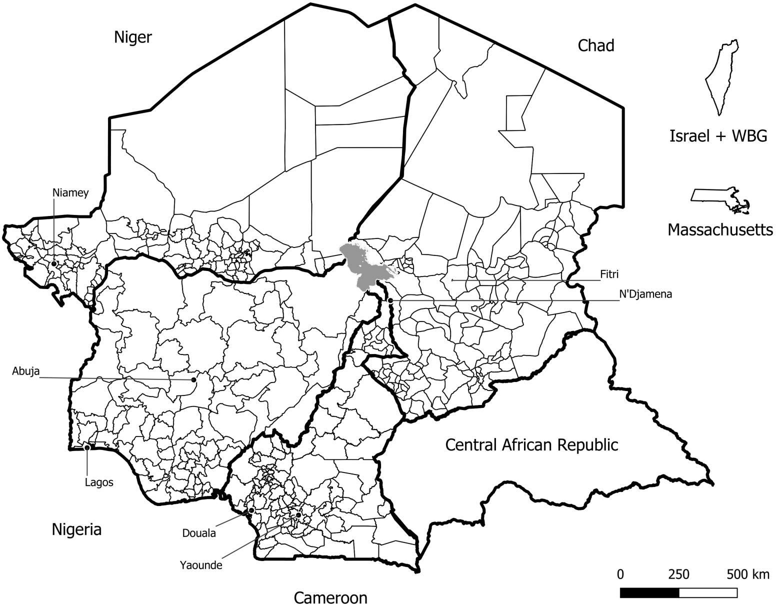
- Effects are a priori ambiguous:
  - Fishing: Less fish over time.
  - Farming: More land but reduced irrigation (small-scale) and economic uncertainty (lack of property rights, infrastructure).
  - Livestock: Less vegetation and less water for cattle herders.
  - Local climate change: water loss $\rightarrow$ less rain and higher temps.
  - Services: Higher transport costs (boats transport goods on the lake). Urban activities centered on servicing the other three sectors.

$\Rightarrow$ Reduced-form results? Pop. moving away from lake over time?

What the former lake areas look like now. Many issues with land development: lack of property rights (whether gvt or communal or private) and infrastructure, geography, insecurity, some of the lake comes back in very rainy years, etc.

Data

- We need localized data before, during, and after the shock.
- Rely on censuses and colonial and post-colonial admin. counts
- Population data at subdistrict level:
  - Cameroon: 113 subdist. (1963-2005) & 47 districts (1956-2005)
  - Chad: 138 subdist. (1948-2009)
  - Niger: 119 subdist. (1951-2017)
  - Nigeria: 83 subdist. (1952-2006) - quality issues with censuses
- City population data (cities = 5,000 at any point in time):
  - Cameroon: 179 cities (1932-2012)
  - Chad: 100 cities (1937-2009)
  - Niger: 115 cities (1931-2012)
  - Nigeria: 1,340 cities (1950-2010) ($>$ 10,000 only)



Cameroon, Chad, Niger & Nigeria: 113, 138, 119 and 83 subdistricts (453 in total). Median/mean area: Equivalent to circle of radius = 28/50km

Panel-DiD Model

- For subdistrict s and year t (regression for each country at a time)

$$ln(Total\ Pop.)_{s,t} = \alpha + \sum_{v} \beta_v \times Proximity\ \ to\ \ Lake_s \times Dummy\ (v\ =\ t)$$
$$+\lambda_s + \theta_t + X_s B_{s,t} + District_s \times t + \mu_{d,t}$$

- *Proximity to Lake*: (-) log Euclidean dist. to the lake. Omitted = c. 1965
- Subdistrict FE and year FE. Conley SEs (100 km).

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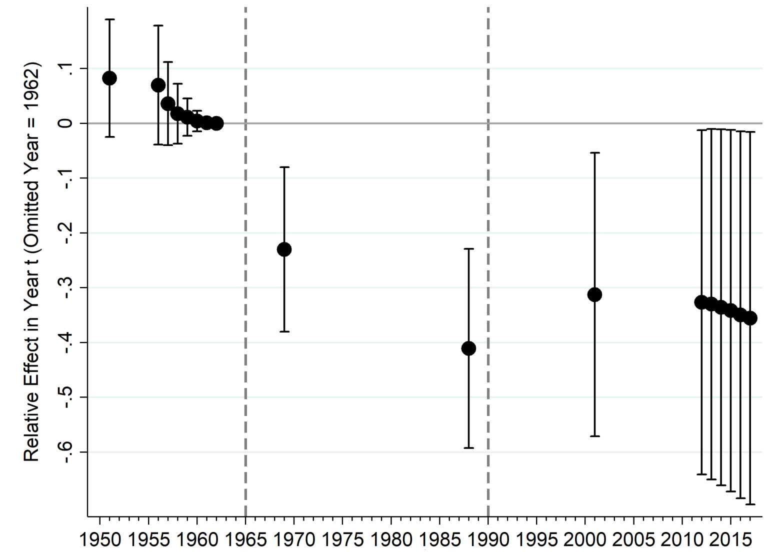
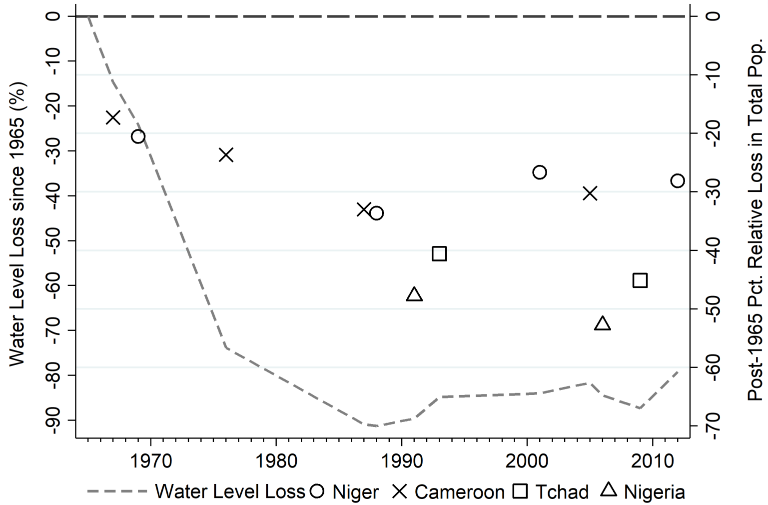
- *Proximity to Lake*: (-) log Euclidean dist. to the lake. Omitted = c. 1965
- Subdistrict FE and year FE. Conley SEs (100 km).
- $X_s B_{s,t}$: Time-invariant controls interacted with year FE:
  - Log Euclidean distances to capital and most populated city.
  - Dummy if crossed by Logone-Chari river system.
  - Latitude as North-South gradient in geography & econ. activity
- District(1960s)-specific linear trends (24-47 depending on country)



Results for Niger (119 subdist. $\times$ 17 yrs = 2,023). Omitted = 1962.

10% confidence intervals.



Avg pop loss c. 1990-2010 = 45-48% (avg elasticity -0.6). Excl. Nigeria the country with less reliable pop data, 35-33% (avg elasticity -0.4).

Analysis on Cities

- Same flexible specification but city-level analysis (city FE)
- Several outcomes:
  - Log (city pop. + 1) in year t *
  - Dummy if city > 5,000 in year t
- If total population grows relatively slower close to the lake, but city population doesn't, urbanization rates increase.

  ⇒ "Refugee" urbanization?

* For each city (i.e. locality > 5,000 at any point during the period of study), we know the exact population level if > 5,000. Imperfect information for city-years where pop. < 5000. We then always replace by 0 and consider log (pop. +1). For Nigeria, information is missing for 5,000. We thus consider 10,000.

Table 3: **Effect of Proximity to the Lake, City Population, Flexible Specification**

Dependent Variable:	Log (City Population + 1) in Year t (City Population = Population if $\geq$ 5,000 (Nigeria = 10,000))			
Country:	Niger	Cameroon	Chad	Nigeria
Omitted Year = Early 60s	(1)	(2)	(3)	(4)
0-150 Km*ca.1990	4.09***	3.65**	-4.41***	0.17
	[1.37]	[1.54]	[1.52]	[1.13]
150-300 Km*ca.1990	2.37**	0.79	-3.53	1.16
	[1.05]	[0.93]	[2.55]	[1.08]
300-450 Km*ca.1990	1.78**	0.34	-2.51***	-0.64
	[0.83]	[1.76]	[0.56]	[0.95]
0-150 Km*ca.2010	0.68	0.00	-0.16	3.07***
	[1.95]	[0.00]	[2.84]	[0.45]
150-300 Km*ca.2010	0.23	0.65***	3.21	1.78***
	[1.63]	[0.22]	[3.12]	[0.56]
300-450 Km*ca.2010	1.57**	2.03**	2.07	-0.52
	[0.71]	[0.88]	[2.03]	[0.46]
City FE, Year FE	Y	Y	Y	Y
District Trends, Controls	Y	Y	Y	Y

Notes: Obs.: Niger: 166 cities x 17 Yrs = 2,822. Cameroon: 179 cities x 18 Yrs = 3,222. Chad: 100 cities x 12 Yrs = 1,200. Nigeria: 1,340 cities x 8 Yrs = 10,720. We omit 1965, 1965, 1964, and 1960, respectively.

Unlike what we observed for total pop., no widespread decline in city pop.

Table 4: **Effect of Proximity to the Lake, Local Climate Change, Flexible Specification**

Country:	Niger	Cameroon	Chad	Nigeria
Benchmark = 1950-1964	(1)	(2)	(3)	(4)
Dependent Variable:	Log Mean Annual Rainfall (mm) in the Subdistrict in Period t			
0-150 Km*(1980-1994)	-0.01	-0.29***	-0.34***	0.00
	[0.03]	[0.02]	[0.05]	[0.04]
150-300 Km*(1980-1994)	0.02	-0.07***	-0.29***	-0.08**
	[0.04]	[0.02]	[0.05]	[0.03]
300-450 Km*(1980-1994)	-0.03	-0.07***	-0.10***	-0.04
	[0.02]	[0.02]	[0.03]	[0.05]
Dependent Variable:	Log Mean Monthly Temperature (Celsius) in the Subdistrict in Period t			
0-150 Km*(1980-1994)	0.028***	0.039***	0.012***	0.000
	[0.002]	[0.006]	[0.005]	[0.004]
150-300 Km*(1980-1994)	0.017***	0.018***	0.006	0.008**
	[0.002]	[0.006]	[0.005]	[0.003]
300-450 Km*(1980-1994)	0.001	0.008	0.001	0.002
	[0.001]	[0.005]	[0.004]	[0.003]
Subdistrict FE, Period FE	Y	Y	Y	Y
District Trends, Controls	Y	Y	Y	Y

Notes: Obs.: Niger: 119 Subdist. x 13 Periods = 1,547. Cameroon: 179 Subdist. x 13 Periods = 3,222. Chad: 100 Subdist. x 13 Periods = 1,200. Nigeria: 1,340 Subdist. x 13 Periods = 10,720. We report the difference

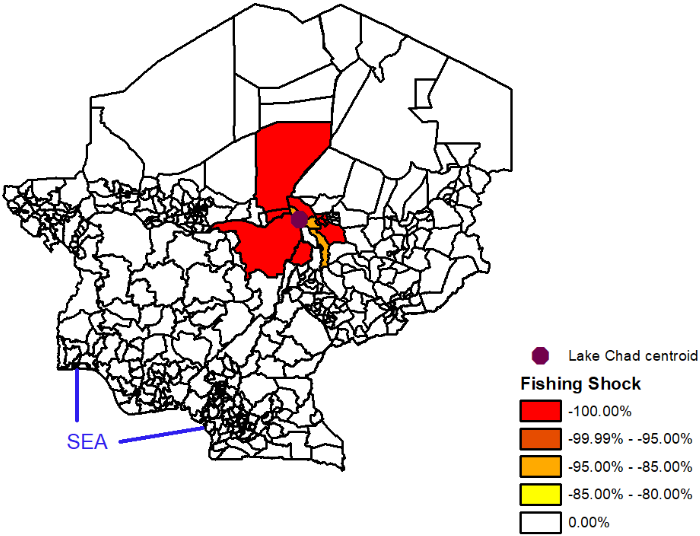
Rainfall losses: 0-30%. Temperature increases: 0-3%.

Quantitative Spatial Model: Set-Up

- Closed economy:
  - Multiple locations (subdistricts) in the four countries
  - Iceberg trade costs τ across subdistricts (weighted centroid)
- Production:
  - Multiple sectors: fishing, livestock, agriculture and an urban sector.
  - One representative firm per sector and location
  - The production function is Cobb-Douglas: labor, water, and land.
  - Agglomeration forces in the urban sector
- Preferences-Nested structure:
  - Sectors + Housing: Cobb-Douglas
  - Varieties: CES (Armington)
- Migration:
  - free migration, within countries, within ethnic groups, no migration.

Calibration

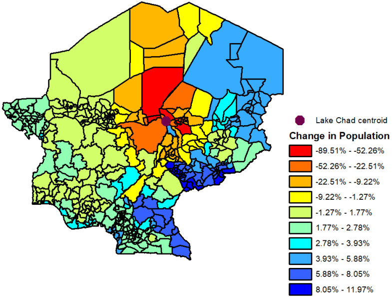
- Farming & livestock: TFP measures based on information from FAO-FGGD on land suitability for crops and livestock.
- Fishing: Same TFP across loc. but amount of water varies by loc.
- Urban: Calibrate TFP with pop. in cities $\geq$ 5K (Nigeria: 10K).
- Expenditure shares: consumer surveys in late 1950s or early 1960s.
- Elasticities (trade, migration, agglo., congestion) from studies
- Trade costs across locations: road networks c. 1965 from Michelin maps that were digitized (paved vs. improved vs. dirt roads)
- Invert the model and recover amenity distribution for each location by matching pops we observe to pops predicted by the model.



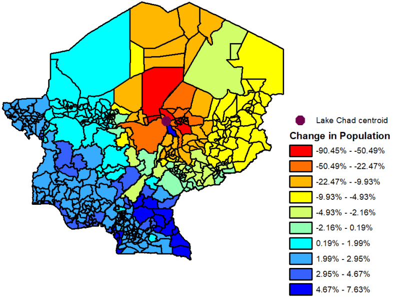
Shock for **fishing sector**: Water loss for shore subdistricts.

Prediction: People move close to sea in Cameroon & Nigeria.

Farming shock Livestock shock

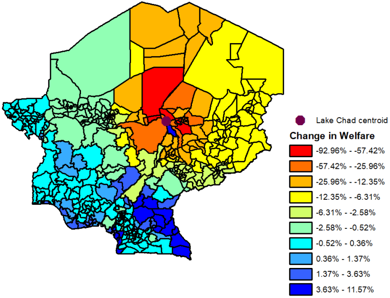


(a) Migration within countries only

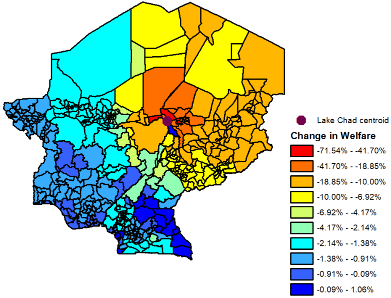


(b) Free Migration (across Countries)

Predicted change in population: (a) Within each country, pop. moving away from lake. One subdistrict close to lake benefits (still has access to Southern pool where water); (b) Pop. moving to Cameroon & Nigeria. Chad loses.



(c) Migration within Countries Only



(d) Free Migration (across Countries)

Predicted change in welfare: Pop. and welfare decreases are correlated. But welfare may decrease despite population increasing, as observed in Chad. Some locations not directly affected experience losses as lose access to certain goods.

Table 5: Aggregate Economic Losses

Panel A: Migration within countries only			
Aglomeration force/Congestion force	$\lambda = 0.32$	$\lambda = 0.12$	$\lambda = 0$
$\gamma = 0.2$	-1.98%	-1.95%	-1.93%
$\gamma = 0.1$	-2.04%	-2.01%	-1.99%
$\gamma = 0.05$	-2.01%	-2.03%	-2.01%
Panel B: Migration across all locations			
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Panel C: No migration			
Aglomeration force/Congestion force	$\lambda = 0.32$	$\lambda = 0.12$	$\lambda = 0$
$\gamma = 0.2$	-4.77%	-5.39%	-5.51%
$\gamma = 0.1$	-4.89%	-5.58%	-5.74%
$\gamma = 0.05$	-4.94%	-5.66%	-5.84%

Aggregate welfare loss: 2%. Not allowing for migration within countries, loss of 5.6%. Migration = margin of adjustment when climate change. However, if migration across countries, loss of 2.6% (> 2%). Indeed, shock leads to less urbanization overall if people can move to other countries' rural areas.

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Table 7: Reduced-Form Effects of Proximity to the Lake - Simulated Data

VARIABLES	(1) Δ ln Welf	(2) Δ ln Welf	(3) Δ ln Pop	(4) Δ ln Pop
Panel A: Migration within countries only				
- log dist. to lake	-0.137*** (0.007)	-0.116*** (0.007)	-0.214*** (0.014)	-0.232*** (0.015)
Observations	453	453	453	453
R-squared	0.434	0.512	0.346	0.362
Panel B: Free migration				
- log dist. to lake	-0.122*** (0.007)	-0.115*** (0.007)	-0.244*** (0.014)	-0.230*** (0.015)
Observations	453	453	453	453
R-squared	0.410	0.423	0.410	0.423
Country FE		X		X
Observations	453	453	453	453

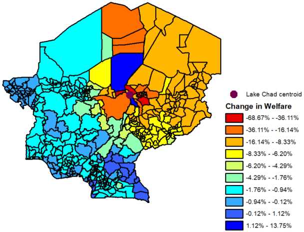
Relative pop loss as function of (-) log distance to lake. For pop, reduced-form -0.4 (excl. Nigeria for which worse pop data). Magnitude lower because various channels not included, e.g. poverty → conflict → poverty.

Table 6: Effects of Road Infrastructure Investments

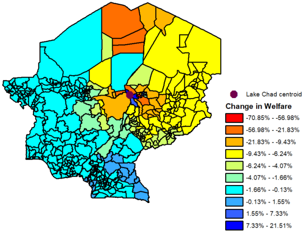
Infrastructure Investment (Paving 20 Unpaved Cells)	Economic Losses (%)		
	(1) $\mu = 0.05$	(2) $\mu = 0.1$	(3) $\mu = 0.2$
Closest to the Lake	1.958%	1.935%	1.879%
Connecting the Lake to the Largest City	1.951%	1.929%	1.875%
Closest to the Largest City	1.981%	1.958%	1.901%

Effects of paving roads. Pave 20 unpaved 0.1*0.1° degree (11*11km) cells: CLOSEST = Closest to Lake; CONNECT = Closest to Lake + on the road to largest city; LARGEST = Closest to largest city. Stronger for CONNECT.

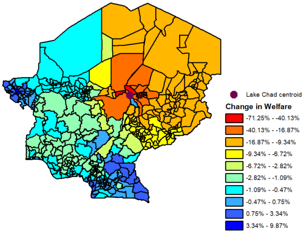
Figure 12: Spatial Distribution: % Δ Welfare - Effects of Paving 20 Unpaved Cells



(a) Cells Closest to the Lake



(b) Cells to Connect the Lake to the Largest City



(c) Cells Closest to the Largest City

Spatial Effects of paving roads. CONNECT helps the most.

Conclusion

Research question

Did the lake's shrinking affect local and aggregate economic growth?

Reduced-form results

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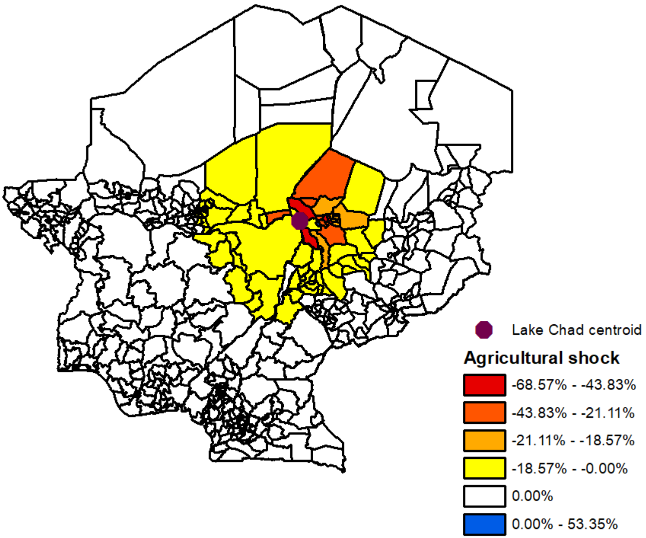
- Novel data subdistrict level 1950s-2010s: total & city pop.
- Much slower pop. growth around lake (water effect dominates). Less negative effects on city pop. → "refugee" urbanization.

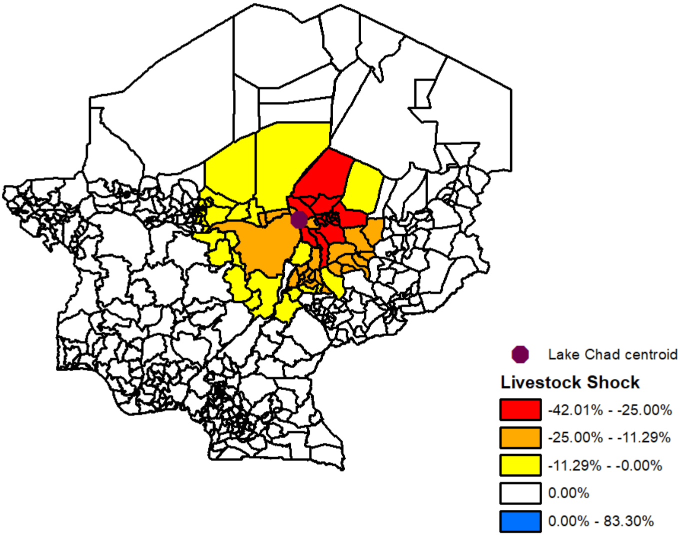
Quantitative Spatial Model

- Agg. welfare loss of 2%. Concentrated close to lake.
- 2.5x higher if no migration. But smaller if across countries.
- Roads connecting lake to largest city have stronger effects.



Shock for **farming sector**: (i) more land (adjusted for pop. increase within former lake area); (ii) loss of irrigation (small-scale); (iii) negative relationships btw yields and rainfall losses as well as temperature increases (main crops)

Back



Shock for **livestock sector**: (i) more land (adjusted for pop. increase within former lake area); (ii) extinction very productive Kuri cattle breed; (iii) negative relationships btw livestock prod. and rainfall (biomass) or temperature (weight)

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