Cooperation over Freshwater Resources in Africa

Latest Updates

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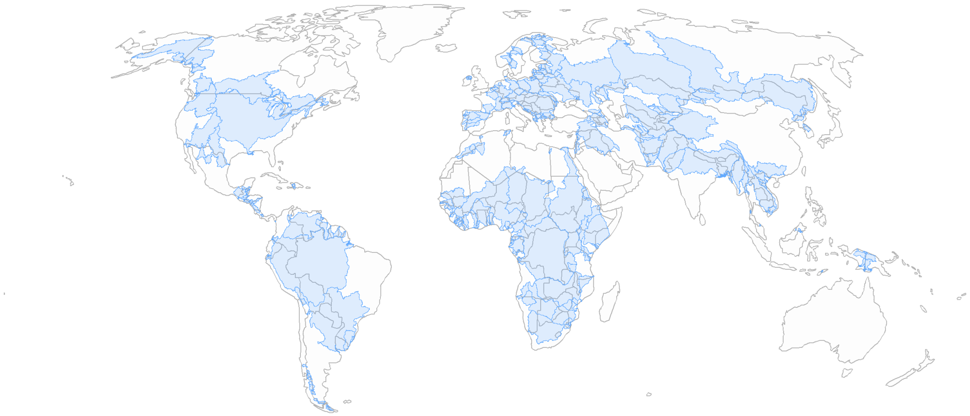
Work (very much) in Progress

April 9, 2024

(Click through recent water-related headlines inc. pictures; tensions on Nile; Colorado River, etc. inc. local examples. TO ADD)

- Over half the world's population lives in transboundary water basins (De Stefano et al., 2017)
- Managing freshwater resources is hard *within* country, much less *across*, even for rich countries
- Cooperation involving formal agreements is hard to interpret (causality $\Leftrightarrow$)

International Water Basins

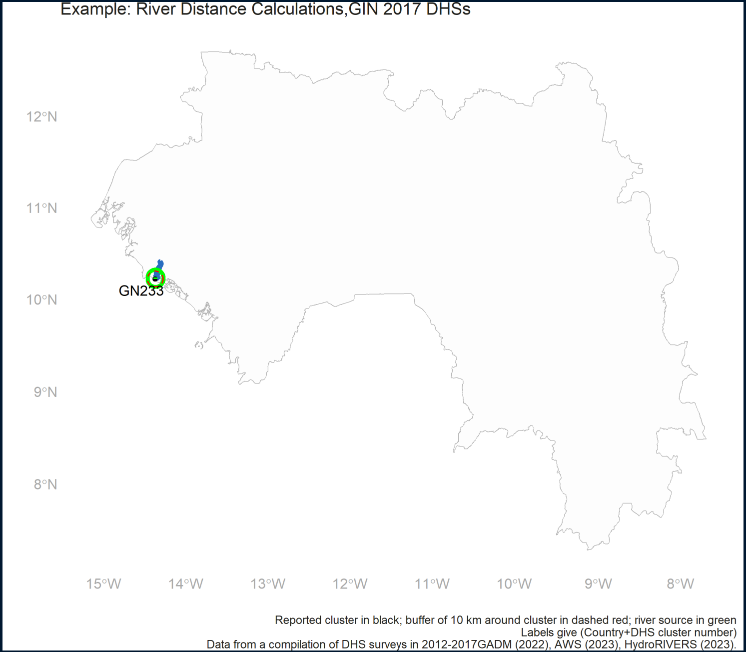


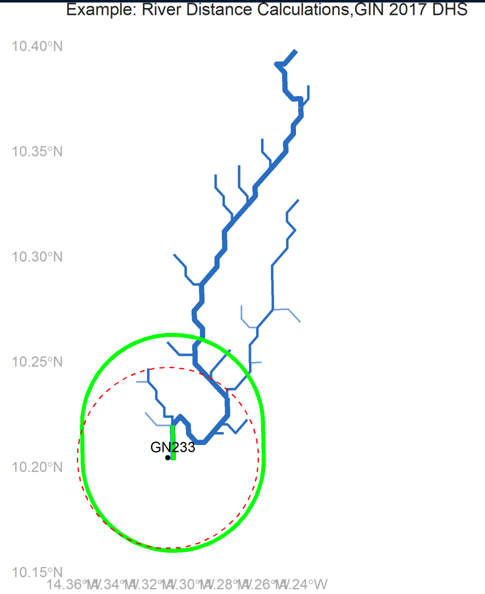
Data from Transboundary Freshwater Dispute Database, Oregon State University 2022

310 total international basins.

- Agriculture accounts for 85% of water withdrawn in Africa (ReliefWeb, 2020). Irrigation is very low ($\approx 7\%$ of ag. land (International Water Management Institute, 2024)). Many communities (e.g. in Sahel) rely on pre- or post-flooding for cropping
- Climate change is affecting levels, variability, and onset of rains (Monerie et al., 2021)
- Water markets are often incomplete or informal themselves (e.g. tankers for drinking water) (Mapunda et al., 2018)
- Many arrangements over water resources are **informal** or **implicit** (Nemarundwe and Kozanayi, 2003)
- Expert opinion on basin-level management has been mixed due to e.g. basin-management organizations lacking power to implement basin-wide policies; opposing goals at varying levels of management; conflict among international states (Wolf, 1999; Wolf et al., 2003)
- It's difficult to tease out how communities comparatively cooperate over their water resources
- (Add case studies, e.g. OMVS)


Morocco
Algeria
Libya
Egypt
Western
Sahara
Saudi Arabia
Mauritania
Mali
Niger
Sudan
Chad
Burkina
Faso
Guinea
Ethiopia
Nigeria
Ghana
Kenya
Gabon
DRC
Tanzania
Mozambique
Zambia
Angola
Madagascar
Zimbabwe
Namibia

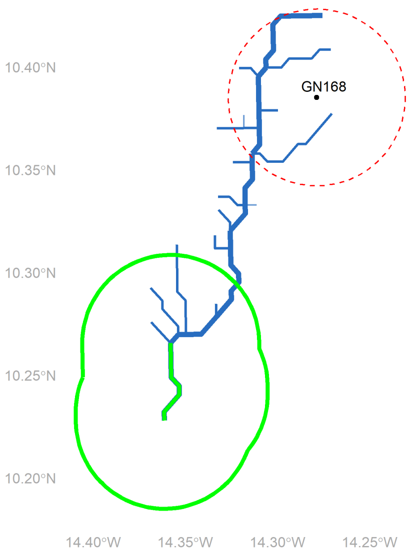

Example: River Distance Calculations,GIN 2017 DHSs
12°N
11°N
10°N
9°N
8°N
GN233
15°W
14°W
13°W
12°W
11°W
10°W
9°W
8°W
Reported cluster in black; buffer of 10 km around cluster in dashed red; river source in green
Labels give (Country+DHS cluster number)
Data from a compilation of DHS surveys in 2012-2017GADM (2022), AWS (2023), HydroRIVERS (2023).



Reported cluster in black; buffer of 5 km around cluster in dashed red; river source in green
Labels give (Country+DHS cluster number, segment vertex number)
Data from DHS (2017)GADM (2022), AWS (2023), HydroRIVERS (2023).


Bandeyehde
Yarita
Wakiriy
Lougame
Madine
Pourou

Example: River Distance Calculations,GIN 2016 DHS



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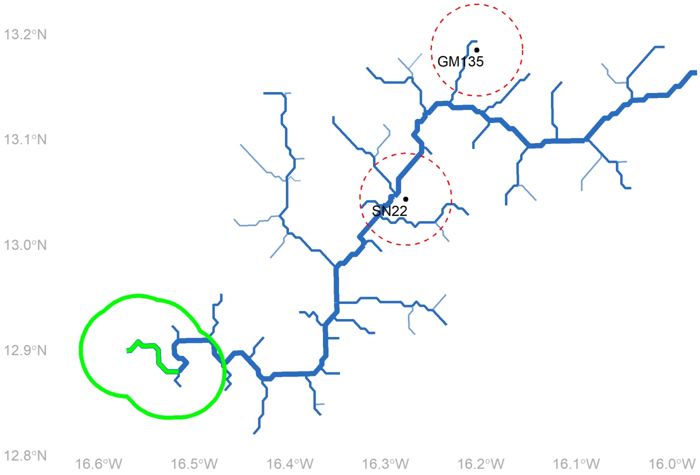
Labels give (Country+DHS cluster number, segment vertex number)
Data from DHS (2016)GADM (2022), AWS (2023), HydroRIVERS (2023).

Example: River Distance Calculations,GMB SEN 2018-2020 DHSs



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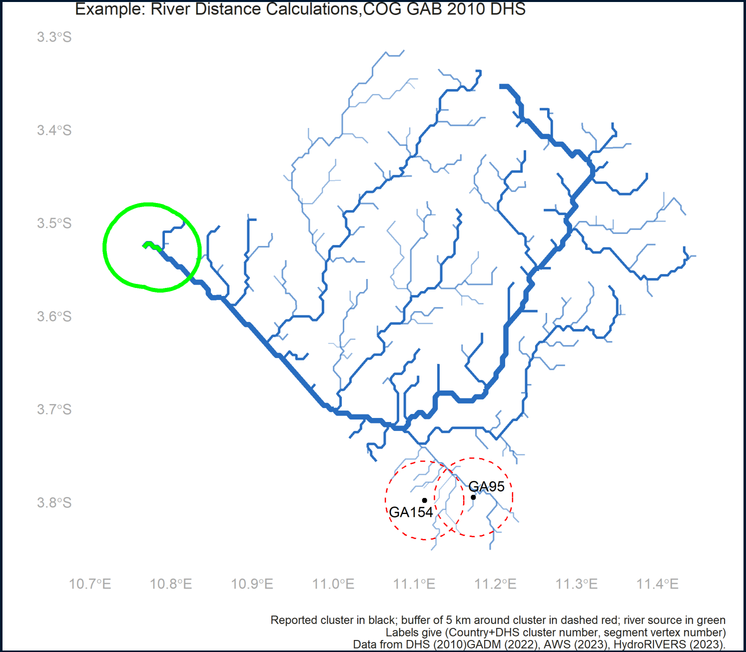
Data from DHS (2018-2020)GADM (2022), AWS (2023), HydroRIVERS (2023).


Example: River Distance Calculations,COG GAB 2010 DHS
3.3°S
3.4°S
3.5°S
3.6°S
3.7°S
3.8°S
GA95
GA154
10.7°E
10.8°E
10.9°E
11.0°E
11.1°E
11.2°E
11.3°E
11.4°E
Reported cluster in black; buffer of 5 km around cluster in dashed red; river source in green
Labels give (Country+DHS cluster number, segment vertex number)
Data from DHS (2010)GADM (2022), AWS (2023), HydroRIVERS (2023).

Research question(s):

How are low-income communities sharing water on rivers *de facto* over time? What (fixed/varying) factors are associated with fuller risk-sharing? (Eventually: How might climate change affect these *de facto* arrangements?)

Strategy:

- **Descriptive:** What's the relationship between rainfall, water availability on rivers, and outcomes for small rivers (i.e. with few towns to contract with)
- **Model:** Self-enforcing contract game: upstream town(s) can allow water to pass to downstream town(s) in exchange for transfers upstream
- **Empirics:** Examine Demographic Health Surveys (DHS); satellite lights; greenness over time, and compare outcomes as a function of precipitation and water flow
- **Identification:** IV / DiD changing **costs** to coordination or **benefits** from cooperation (current example: cell-tower roll-out)

Short-term Goal: trace out "contracts" on rivers under different states of precipitation in up- and downstream, see how rainfall affects water flow (using river widths 1984-2020) affects (final outcome) infant mortality and how this varies according to the usual suspects (e.g. borders, language barriers, ethnicity differences, conflict prevalence)

Infant mortality is sensitive to water availability:

- Water availability affects: agricultural outcomes (e.g. nutrition); hygiene (e.g. diarrhea); disease vectors (e.g. malaria). All these have been found to influence infant mortality (e.g.(Persson et al., 2012))

Spatio-temporal comparability:

- Retrospectively asking about fertility isn't subject to (too much) recall bias (cite)
- Can build out panel-esque information from many cross-sections over a wide geography (71k towns,30-some countries), 1954-now

Mechanisms also of interest:

- Mechanisms for water $\rightarrow$ infant mortality include: in-HH asset accumulation (can get some with DHS household); agricultural productivity and overall community incomes (satellite data: lights, greenness (caveat, only 1992-on))

Not the only analysis?:

- Country-specific section with... better data? better time? more institutional analysis? really lucky identification?
- e.g. dams on River Senegal re-flooding
- Big caveat: short-term for now, *given* dam choice

Water scarcity and tensions:

Exploring infant mortality, a less extreme variable than conflict ("latent"); eventually add remote-sensing data for mechanisms (satellite lights, farm yields, greenness) (McGuirk and Nunn, ming; Burke et al., 2015) / child mortality (Persson et al., 2012)

Water agreements and cooperation/externalities:

Informal arrangements, can bring in formal arrangements and whether those mitigate. Novel(?) use of DHS data to look at revealed outcomes (Wolf, 1999; Dinar et al., 2019)

Externalities over water:

Primarily quantity and upstream-downstream relationships rather than common-pool considerations (yes, groundwater's missing here. Unclear if that's quantitatively important in this context over this time span.) (Lipscomb and Mobarak, 2017; Ryan and Sudarshan, 2022)

Limited-commitment risk-sharing:

New(?) application (and modeling !) (Ligon et al., 2002; Meghir et al., 2019)

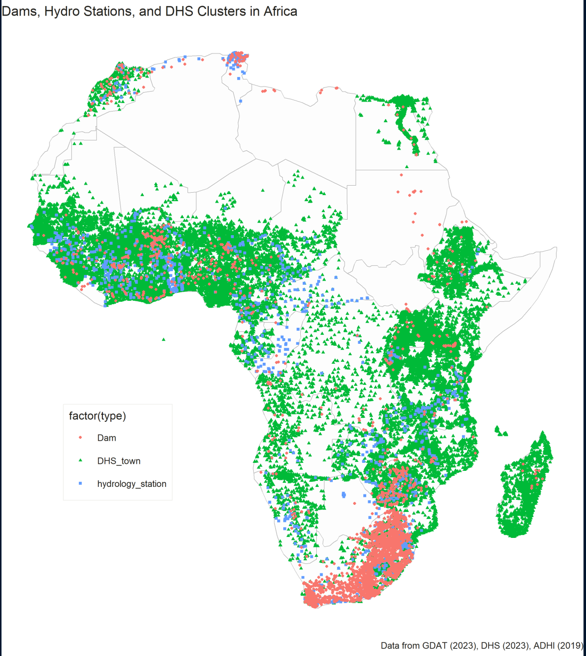
Mortality data: Demographic Health Surveys (DHS)

Over 320 surveys in over 90 countries over past 30 years, nationally representative.
Currently just using Africa (over 100 surveys)
DHSs are cross-sections; but mortality data is retrospective
Why not a panel? We would observe households at different life cycle stages.
Interpretation murkier. (Thoughts?)

Rainf: European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5): models disciplined by observations. Aggregated to average monthly rainfall over the year

River locations: HydroSHEDS river networks (plus R `riverdist`) (alt. Digital Elevation Model (DEM))

Also: Global Administrative Areas (GADM) (no border changes yet?); **Global Long Term River Width**: satellite data capturing river widths over time (1984-2020); GDAT dams panel


Dams, Hydro Stations, and DHS Clusters in Africa
factor(type)
Dam
DHS_town
hydrology_station
Data from GDAT (2023), DHS (2023), ADHI (2019)

Statistic	N	Min	Mean	Median	Max	St. Dev.
Year	616,500	1,956	2,000.00	2,001	2,022	10.95
Average annual precip. (mm/month)	616,500	0.00	0.003	0.003	0.02	0.003
Long-run avg. precip (mm/month)	616,500	0.0000	0.003	0.003	0.01	0.003
Annual precipitation Z-score	616,500	−3.06	−0.10	−0.19	8.59	0.86
3-year avg. precip.	616,500	0.0000	0.003	0.003	0.02	0.003
5-year avg. precip.	616,500	0.0000	0.003	0.003	0.02	0.003
Infant Mortality (/1000 births)	616,500	0	68.08	0	1,000	251.89
Infant Mort., Exposure-weighted	616,500	0.00	34.15	0.00	1,000.00	147.53
Rural	616,500	0	0.62	1	1	0.49
On a Dammed River	616,500	0	0.15	0	1	0.35
On a River with Width Obs	616,500	0	0.52	1	1	0.50
On a River with Hydro Station	616,500	0	0.17	0	1	0.38
N infants per town	616,500	0.50	51.65	47.00	178.00	26.38
N infants per year	616,500	0.50	7,913.36	8,950.50	10,813.00	2,715.02
N infants/town/year	616,500	0.50	2.54	2.00	13.50	1.69

N is infant-by-year. Precipitation data from Hersbach et al. (2020) in mm per month, averaged over the year. Mortality data from over 100 DHS surveys. Currently unweighted by DHS weights for survey probabilities. River data from HydroATLAS (2022), additional calculations use `riverdist` package in R. Data restricted to 60% of cluster-years on rivers with $<$ 100 towns (7223 clusters)

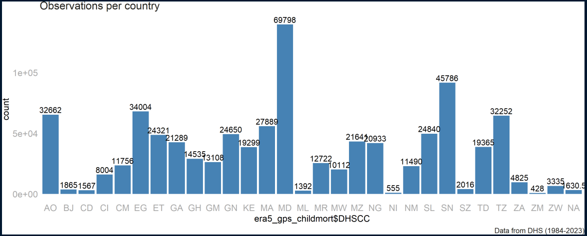
Summary Statistics

Statistic	N	Min	Mean	Median	Max	St. Dev.
Year	13,675	1,965	1,995.91	1,997	2,014	9.53
Average annual precip. (mm/month)	13,675	0.0000	0.001	0.001	0.004	0.001
Long-run avg. precip (mm/month)	13,675	0.0001	0.001	0.001	0.002	0.001
Annual precipitation Z-score	13,675	−1.67	0.12	−0.002	4.99	0.95
3-year avg. precip.	13,675	0.0000	0.001	0.001	0.003	0.001
5-year avg. precip.	13,675	0.0001	0.001	0.001	0.003	0.001
Infant Mortality (/1000 births)	13,675	0	40.07	0	1,000	196.14
Infant Mort., Exposure-weighted	13,675	0.00	20.30	0.00	1,000.00	115.24
Rural	13,675	0	0.40	0	1	0.49
On a Dammed River	13,675	0	0.22	0	1	0.41
On a River with Width Obs	13,675	0	0.24	0	1	0.43
On a River with Hydro Station	13,675	0	0.36	0	1	0.48
N infants per town	13,675	0.50	31.43	27.00	96.00	17.36
N infants per year	13,675	131.00	7,862.97	8,575.50	10,813.00	2,649.46
N infants/town/year	13,675	0.50	1.66	1.50	6.50	1.08

N is infant-by-year. Precipitation data from Hersbach et al. (2020) in mm per month, averaged over the year. Mortality data from over 100 DHS surveys. Currently unweighted by DHS weights for survey probabilities. River data from HydroATLAS (2022), additional calculations use `riverdist` package in R. Data restricted to 60% of Namibia's-years on rivers with $<$ 100 towns (293 clusters)

	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	28.826			28.703		
	(0.301)			(0.304)		
Annual avg precip	-505.023	62.807	473.936	-497.825	62.320	472.602
	(440.373)	(440.102)	(452.597)	(440.421)	(440.111)	(452.599)
5-year avg precip	2198.505	6012.515	-515.231	2147.543	6219.381	183.356
	(448.198)	(1026.209)	(1066.263)	(448.892)	(1134.809)	(1170.488)
5-yr precip × Dist to source				4.700	-11.690	-39.428
				(1.705)	(27.259)	(27.332)
Mean	34.3	34.3	34.3	34.3	34.3	34.3
Cluster FE	N	Y	Y	N	Y	Y
Year FE	N	N	Y	N	N	Y
Num.Obs.	533100	533100	533100	533100	533100	533100
R2	0.001	0.033	0.036	0.001	0.033	0.036

Notes:
Outcome is infant deaths per 1000 infants observed. Precipitation data from ERA5 (2023), in millimeters per month (averaged over the year); river data from HydroSHEDS (2022); DHS surveys from 1988 to 2023, covering 7223 towns on 1101 rivers over 1957-2022 (omitting Madagascar).



Observations per country
count
1e+05
5e+04
0e+00
32662
1865
1567
8004
11756
34004
24321
21289
14535
13108
24650
19299
27889
69798
1392
12722
10112
21641
20933
555
11490
24840
45786
2016
19365
32252
4825
428
3335
630.5
AO BJ CD CI CM EG ET GA GH GM GN KE MA MD ML MR MW MZ NG NI NM SL SN SZ TD TZ ZA ZM ZW NA
era5_gps_childmort$DHSCC
Data from DHS (1984-2023)

Analysis:

1. Write out specifications and show
2. Add in river widths and distances (placement of width measurement is frustrating)

Refine for rest of Africa, then global?
Data:

1. Trace out implicit contracts
2. Give a interesting correlates of better risk-sharing (e.g.)

    Economic: Basin management committee, water market in existence, within a country fossil fuel subsidies across areas? (defines price for pumping)
    Socio-cultural: religion, ethnicity, language
    Physical: ruggedness, potential yields, dam/canal infrastructure

Model:

1. Go back to model
2. Work through findings of edited model vs. original(s)

- Potential yield (richer downstream, better contracts?)
- Technology change (better outside insurance, better contracts?) e.g. cell tower roll-out
- Introduction of water markets (not too common in low-income?)
- **Other ideas?**

Setting:

- Two towns $i \in \{u, d\}$ (upstream, downstream)
- Infinite horizon, discount factor δ
- Each period $t = 1, 2, \ldots$, i receives water endowment $e^i(s) > 0$ for state s in finite $\mathcal{S}$
- Can transform water into final good with concave production function f (ignoring other inputs for now)
- Water and final good are non-storable (can't save)

Current write-up is a mashup of Ansink and Ruijs (2008) and Ligon et al. (2002)

Transfers:

- Water can be sent downstream with quantity $\omega \leq e^u(s)$, but not upstream
- Final good y can be transferred: τ are transfers ($\tau < 0$ is a transfer from u to d) (ignoring other trade for now)

Production:

- Water w^i available for production (assume for now downstream uses it all)

$$w^u = e^u(s) - \omega$$
$$w^d = e^d(s) + \omega$$

- Final good production:

$$y^i = f(w^i), f' > 0, f'' < 0$$

Representative consumer in each town is risk-averse, with period expected utilities over consumption $c^i \geq 0$ of the final good (ignoring direct consumption of water)

$u' > 0, u'' < 0$ (upstream utility $u(\cdot)$)
$v' > 0, v'' < 0$ (downstream utility $v(\cdot)$)

In autarky, ratio of marginal utilities in state s

$$\xi_s := \frac{u'(f(e^u(s)))}{v'(f(e^d(s)))}$$

Assume $\exists$ at least two states s, r s.t.

$$\xi_s \neq \xi_r$$

Otherwise autarky is first-best

Timing:

1) State s (and therefore endowments $e^u(s)$ and $e^d(s)$) are observed by both parties
2) (To keep it simple) Upstream and downstream simultaneously decide water transfers $\omega(s)$, consumption transfers $\tau(s)$. And production occurs net of these transfers

States:

Markov process: π_{sr} transition probability from s to r

$\pi_{sr} > 0$ for all r, s

Whatever correlation you want between water "streams"

No outside credit

Consequences for reneging

Loss of future insurance forever

- For future loss large enough, full insurance
- If δ small enough, only autarky is feasible
- Focus on the middle cases, partial insurance

For s_t the state in time t, define

- Contract $\mathcal{T}(\cdot)$ for each t and each history $h_t = (s_1, s_t, \ldots, s_t)$
- The contract defines final-good transfer $\tau(h_t)$ from downstream to upstream and water transfer $\omega(h_t)$ from upstream to downstream
  - $\tau(h_t) < 0$ is a transfer from upstream to downstream
  - $h_{t-1} = \varnothing$ for $t = 1$

Define $U_t(h_t)$ as the expected utility gain of honoring vs. one-time reneging for upstream under contract $\mathcal{T}$, history h_t, and analogously $V_t(h_t)$ for downstream.

$$\begin{aligned}
&U_t(h_t) = \\
&\qquad u\left(f[e^u(s_t) - \omega(h_t)] + \tau(h_t)\right) - u\left(f[e^u(s_t)] + \tau(h_t)\right) + \quad \text{(SR gain)} \\
&\qquad \mathbb{E}\left\{\sum_{j=t+1}^{\infty} \delta^{j-t}\left[u\left(f[e^u(s_j) - \omega(h_j)] + \tau(h_j)\right) - u(f[e^u(s_j)])\right]\right\} \quad \text{(LR gain)}
\end{aligned} \tag{1}$$

$$
\begin{aligned}
U_t(h_t) = & \\
& u\left(f[e^u(s_t) - \omega(h_t)] + \tau(h_t)\right) - u\left(f[e^u(s_t)] + \tau(h_t)\right) + \quad \text{(SR gain)} \\
& \mathbb{E}\left\{\sum_{j=t+1}^{\infty} \delta^{j-t}\left[u\left(f[e^u(s_j) - \omega(h_j)] + \tau(h_j)\right) - u(f[e^u(s_j)])\right]\right\} \quad \text{(LR gain)}
\end{aligned} \tag{1}
$$

$$
\begin{aligned}
V_t(h_t) = & \\
& u\left(f[e^d(s_t) + \omega(h_t)] - \tau(h_t)\right) - u\left(f(e^d(s_t) + \omega(h_t)\right) + \quad \text{(SR gain)} \\
& \mathbb{E}\left\{\sum_{j=t+1}^{\infty} \delta^{j-t}\left[u\left(f[e^d(s_j) + \omega(h_j)] - \tau(h_j)\right) - u(f[e^d(s_j)]\right]\right\} \quad \text{(LR gain)}
\end{aligned} \tag{2}
$$

$$U_t(h_t) =$$

$$u\left(f[e^u(s_t) - \omega(h_t)] + \tau(h_t)\right) - u\left(f[e^u(s_t)] + \tau(h_t)\right) + \quad \text{(SR gain)}$$

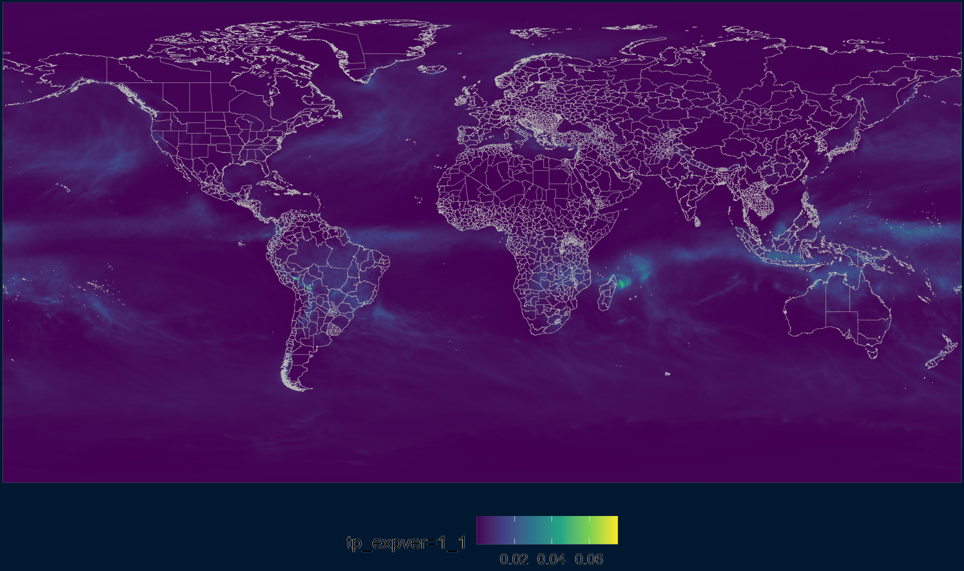
$$\mathbb{E}\left\{\sum_{j=t+1}^{\infty} \delta^{j-t}\left[u\left(f[e^u(s_j) - \omega(h_j)] + \tau(h_j)\right) - u(f[e^u(s_j)])\right]\right\} \quad \text{(LR gain)}$$

Sustainability Constraints (SCs):

$$U_t(h_t) \geq 0 \tag{3}$$

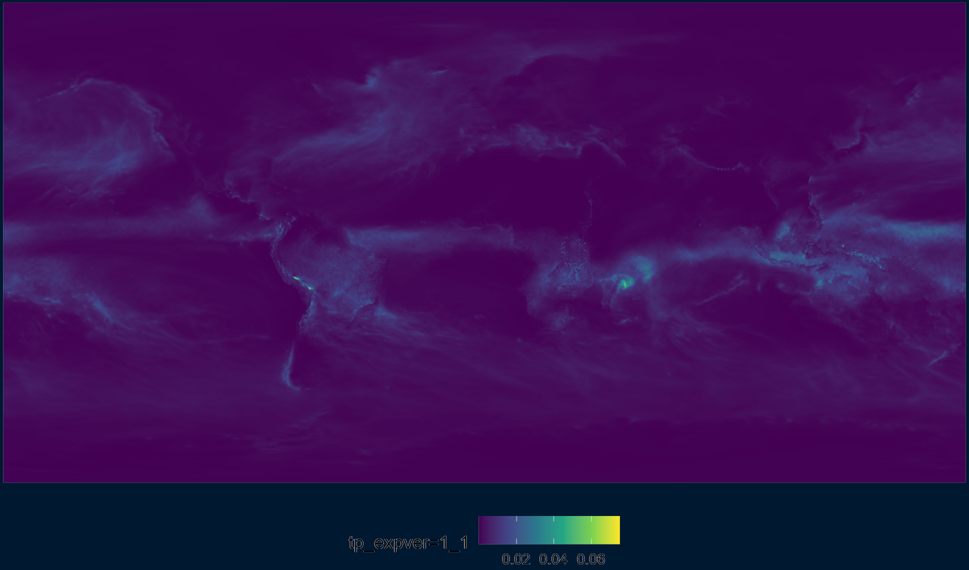
$$V_t(h_t) \geq 0 \tag{4}$$

Rainfall Data
More Visualization

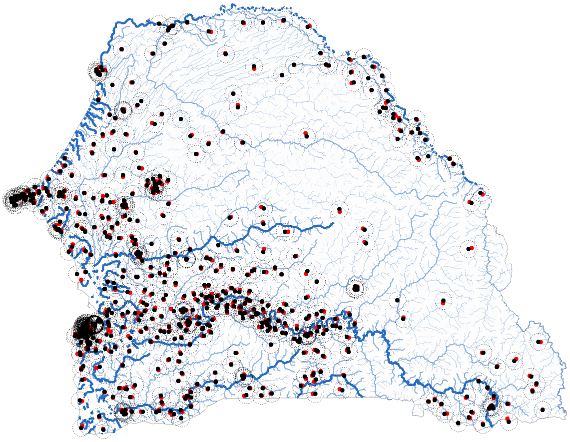


Rainfall Data

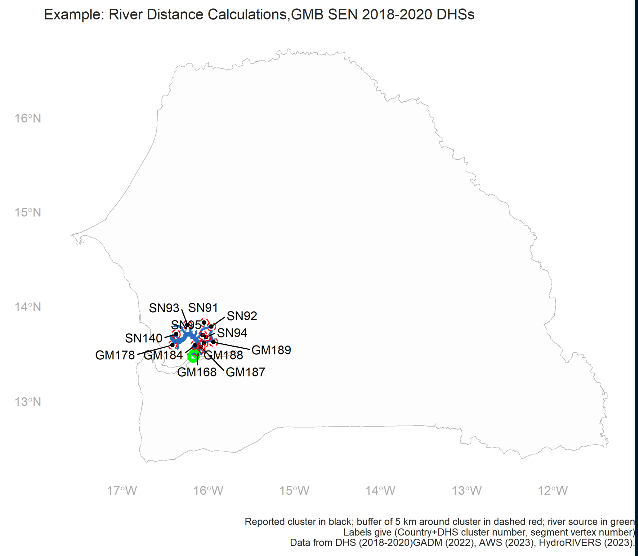
More Visualization

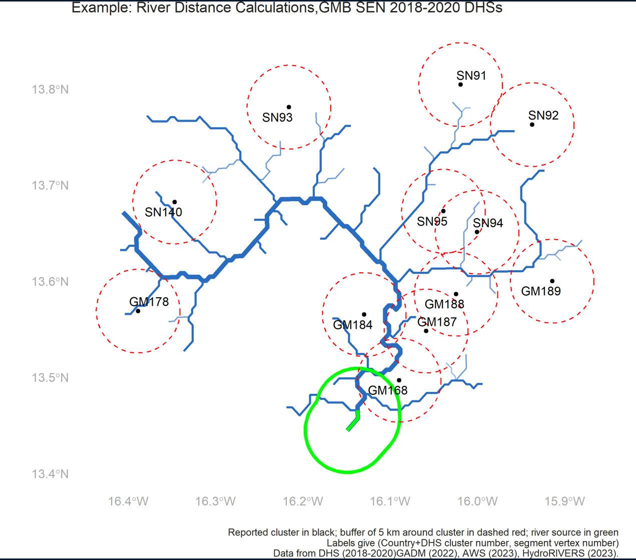


Survey Clusters and Snapping to River Segments GMB SEN, DHS 2018 to 2020



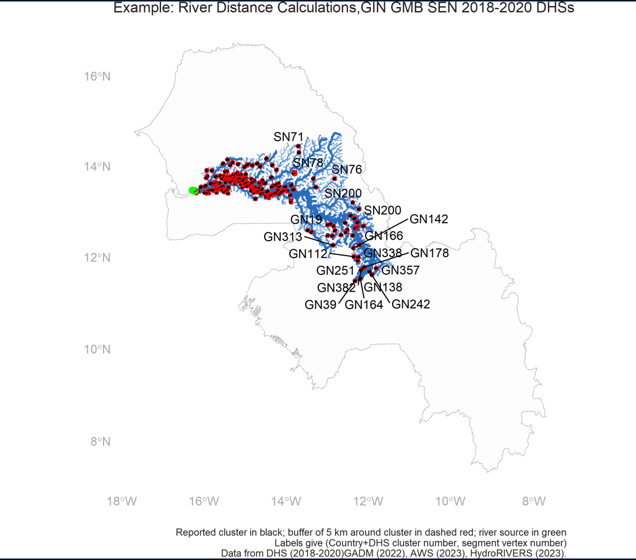
Snapped points in red; original cluster in black; buffer of 10 km around DHS clusters.
Data from DHS (2018 - 2020), GADM (2022), HydroRIVERS (2023).


Example: River Distance Calculations,GMB SEN 2018-2020 DHSs
16°N
15°N
14°N
13°N
17°W
16°W
15°W
14°W
13°W
12°W
SN93
SN91
SN92
SN95
SN94
SN140
GM189
GM178
GM184
GM188
GM168
GM187
Reported cluster in black; buffer of 5 km around cluster in dashed red; river source in green
Labels give (Country+DHS cluster number, segment vertex number)
Data from DHS (2018-2020)GADM (2022), AWS (2023), HydroRIVERS (2023).


Example: River Distance Calculations,GMB SEN 2018-2020 DHSs
13.8°N
13.7°N
13.6°N
13.5°N
13.4°N
16.4°W
16.3°W
16.2°W
16.1°W
16.0°W
15.9°W
SN93
SN91
SN92
SN140
SN95
SN94
GM178
GM184
GM188
GM187
GM189
GM168
Reported cluster in black; buffer of 5 km around cluster in dashed red; river source in green
Labels give (Country+DHS cluster number, segment vertex number)
Data from DHS (2018-2020)GADM (2022), AWS (2023), HydroRIVERS (2023).

River Networks

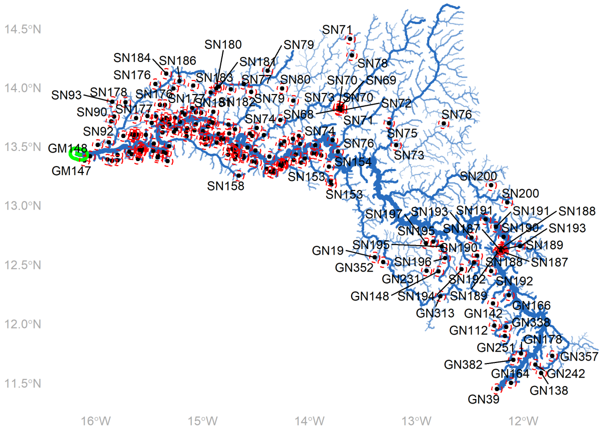
Back to Main River Network



River Networks

Back to Main River Network

Example: River Distance Calculations,GIN GMB SEN 2018-2020 DHSs



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Data from DHS (2018-2020)GADM (2022), AWS (2023), HydroRIVERS (2023).

Summary Statistics

Full Sum Stats

Statistic	N	Min	Mean	Median	Max	St. Dev.
Year	15,005	1,988	2,007.05	2,010	2,018	8.43
Average annual precip. (mm/month)	15,005	4.13	44.08	38.30	132.79	25.66
Annual precipitation SD (mm/month)	15,005	6.03	74.05	66.46	238.66	39.06
Annual precipitation Z-score	15,005	−0.83	−0.54	−0.57	2.67	0.27
Neonatal Mort. Rate (NNMR)	15,003	0.00	29.87	16.26	500.00	40.53
Infant Mortality Rate (IMR)	15,003	0.00	51.12	41.67	600.00	54.12
Under-5 Mort. Rate (U5MR)	14,999	0.00	87.16	70.81	602.32	79.77
Under-10 Mort. Rate (U10MR)	14,993	0.00	100.08	82.54	625.71	85.46
NNMR Weighted Number (WN)	15,005	0	26.47	21	233	20.58
IMR WN	15,005	0	32.84	27	297	25.10

N is number of cluster-by-years, for clusters on rivers intersecting with Senegal. Precipitation data from Hersbach et al. (2020) in mm per month, averaged over the year. Border data from GADM (2022). Mortality data from various DHS surveys. NNMR denotes neonatal mortality rate (months 0-1) per 1,000 live births; IMR denotes infant (months 0-12) mortality rate per 1,000 live births, calculated with modification of the R package `DHS.rates`. Weighted numbers are DHS weights for survey probabilities. Mortality truncated between median and 90th percentile due to small exposed populations.

Summary Statistics Full Sum Stats

Statistic	N	Min	Mean	Median	Max	St. Dev.
Year	8,624	1,988	2,009.49	2,012	2,019	6.45
Cluster distance (m)	8,624	475.53	42,496.11	25,383.45	251,488.90	47,437.44
International	8,624	0	0.002	0	1	0.04
Cross-Adm 1 (state)	8,624	0	0.24	0	1	0.43
Cross-Adm 2 (county)	8,624	0	0.60	1	1	0.49
Urban U, Urban D	8,624	0	0.22	0	1	0.41
Urban U, Rural D	8,624	0	0.05	0	1	0.22
Rural U, Urban D	8,624	0	0.24	0	1	0.43
Rural U, Rural D	8,624	0	0.49	0	1	0.50
(NNMR U)/(NNMR D)	8,624	0.12	1.23	1.09	7.74	0.73
NNMR Weighted N (U)	8,624	15	51.70	49	166	25.93
NNMR Weighted N (D)	8,624	15	41.85	35	183	25.66
(IMR U)/(IMR D)	8,624	0.34	1.19	1.08	3.62	0.52
IMR Weighted N (U)	8,624	15	51.17	47	174	25.77
IMR Weighted N (D)	8,624	15	41.42	34	183	25.26

N denotes a dyad-year, only dyad-years with NNMR and IMR within 50-90th percentiles (to avoid small sample infinite values). Cluster distance is along-river flow-connected distance between dyads. International denotes crossing an international border; Cross-Adm 1 is crossing a state/province border; Cross-Adm 2 is crossing a county/district border. Urban U, Urban D denotes urban up and downstream clusters.

Summary Statistics

Full Sum Stats

Statistic	N	Min	Mean	Median	Max	St. Dev.
Year	181,020	1,988	2,006.27	2,011	2,019	9.53
Cluster distance (m)	181,020	434.98	36,429.00	4,138.88	292,775.30	49,679.83
International	181,020	0	0.001	0	1	0.03
Cross-Adm 1 (state)	179,870	0	0.23	0	1	0.42
Cross-Adm 2 (county)	179,870	0	0.77	1	1	0.42
Urban U, Urban D	181,020	0	0.55	1	1	0.50
Urban U, Rural D	181,020	0	0.05	0	1	0.21
Rural U, Urban D	181,020	0	0.25	0	1	0.44
Rural U, Rural D	181,020	0	0.15	0	1	0.36
(NNMR U)/(NNMR D)	118,319	0.00	Inf.00	1.28	Inf.00	
NNMR Weighted N (U)	181,020	0	38.49	32	236	30.56
NNMR Weighted N (D)	181,020	0	28.04	22	236	23.48
(IMR U)/(IMR D)	141,614	0.00	Inf.00	1.26	Inf.00	
IMR Weighted N (U)	181,020	0	38.22	32	233	30.13
IMR Weighted N (D)	181,020	0	27.84	22	233	23.12

N denotes a dyad-year, all dyad-years included. Cluster distance is along-river flow-connected distance between dyads. Internation denotes crossing an international border; Cross-Adm 1 is crossing a state/province border; Cross-Adm 2 is crossing a county/district border. Urban U, Urban D denotes urban up and downstream clusters.

- Because of Markov structure and since the SCs are forward-looking, sustainable continuation contracts depend on current state s only
- Pareto frontier at time t state s depends on s and not past history
- **Want to Know**: Shape of Pareto frontier and where it's defined
- **First need:**
    1. Convexity of set of sustainable contracts
    2. Convexity of set of sustainable discounted surpluses (i.e. $\exists$ a sustainable contract delivering such surpluses) for each representative consumer

Show that a convex combination of two sustainable contracts is a sustainable contract:

- For $\alpha \in (0,1)$, consider two original contracts $\mathcal{T}(\cdot) = \{\tau(\cdot), \omega(\cdot)\}$ and $\hat{\mathcal{T}}(\cdot) = \{\hat{\tau}(\cdot), \hat{\omega}(\cdot)\}$, and define the consumption and water transfers respectively after each history h_t to as follows:

$$\alpha\tau(h_t) + (1-\alpha)\hat{\tau}(h_t)$$

$$\alpha\omega(h_t) + (1-\alpha)\hat{\omega}(h_t)$$

- $u(\cdot)$ and $v(\cdot)$ are concave, so this new average contract offers at least the average of surpluses from the original $\mathcal{T}$ and $\hat{\mathcal{T}}$ for both consumers from any history h_t, so SCs (Equations 3 and 4) hold, i.e. this is a sustainable contract.

« Include subset of characterization from original Ligon et al. (2002), see what might be different » Additional Slides

Because of

1) Markov structure (can be irreducible)
2) Efficient contract $\Rightarrow$ efficient continuation contract
3) Concavity of period utility functions

The set of sustainable discounted surpluses for each household is an interval!

Because of

1) Markov structure (can be irreducible)

2) Efficient contract $\Rightarrow$ efficient continuation contract

3) Concavity of period utility functions

The set of sustainable discounted surpluses for each household is an interval!

For Upstream: $[\underline{U}_s, \bar{U}_s]$, and $\underline{U}_s \geq -P_1(s)$

For Downstream: $[\underline{V}_s, \bar{V}_s]$, and $\underline{V}_s \geq -P_2(s)$

Let $V_s(U_s)$ be the ex-post Pareto efficient frontier.

Goal: Be on the Pareto Frontier $V_s(U_s)$

$$V_s(U_s) = \max_{\tau_s, (U_r)_{r=1}^{S}} (v(y_2(s)) + \tau_s) - v(y_2(s)) + \delta \sum_{r=1}^{S} \pi_{sr} V_r(U_r)$$

Subject to:

1) Upstream getting surplus at least U_s (LM: λ)
2) Upstream not walking away (LM: ϕ_r)
3) Downstream not walking away (LM: μ_r)
4) Upstream's nonnegativity of consumption (LM: ψ_1)
5) Downstream's non-negativity of consumption (LM: ψ_2)

Characterization: $\lambda_r = \frac{v'}{u'} - \frac{\psi_1 - \psi_2}{u'} = -V_r'(U_r)$

Proposition 1: Constrained-Efficient Contract

A constrained-efficient contract is a transfer scheme where there exist S state-dependent intervals $[\underline{\lambda}_r, \bar{\lambda}_r]$, $r = 1, 2, \ldots, S$ such that $\lambda(h_t)$ is given by, for r the state at $t+1$:

$$\lambda(h_{t+1}) = \begin{cases} \underline{\lambda}_r & \text{if } \lambda(h_t) < \underline{\lambda}_r := -V_r'(\underline{U}_r) \\ \lambda(h_t) & \text{if } \lambda(h_t) \in [\underline{\lambda}_r, \bar{\lambda}_r] \\ \bar{\lambda}_r & \text{if } \lambda(h_t) > \bar{\lambda}_r := -V_r'(\bar{U}_r). \end{cases} \tag{5}$$

This characterizes the contract completely for initial value λ_0

- If you can get first-best, don't change λ
- If you can't, change as little as possible to get into the new interval

Main Slides

- IID income shocks, no punishments
- Two states y_h, y_ℓ
- Each HH suffers loss d with probability $p \in (0,1)$
- Identical log preferences $u(c) = v(c) = log(c)$

Identical prefs $\Rightarrow \xi_{hh} = \xi_{\ell\ell} = 1$

- IID income shocks, no punishments
- Two states y_h, y_ℓ
- Each HH suffers loss d with probability $p \in (0, 1)$
- Identical log preferences $u(c) = v(c) = log(c)$

Low period:

$$y_\ell = y_h - d$$

Expected income per period:

$$y_h - pd$$

- IID income shocks, no punishments
- Two states y_h, y_ℓ
- Each HH suffers loss d with probability $p \in (0, 1)$
- Identical log preferences $u(c) = v(c) = log(c)$

Low period:

$$y_\ell = y_h - d$$

Expected income per period:

$$y_h - pd$$

Four states (Upstream,Downstream): $(h\ell), (hh), (\ell\ell), (\ell h)$

- IID income shocks, no punishments
- Two states y_h, y_ℓ
- Each HH suffers loss d with probability $p \in (0, 1)$
- Identical log preferences $u(c) = v(c) = log(c)$

Low period:

$$y_\ell = y_h - d$$

What's the full-insurance transfer?

- IID income shocks, no punishments
- Two states y_h, y_ℓ
- Each HH suffers loss d with probability $p \in (0,1)$
- Identical log preferences $u(c) = v(c) = log(c)$

Low period:

$$y_\ell = y_h - d$$

What's the full-insurance transfer?

$\tau_{h\ell} = \frac{d}{2}$, Upstream gives Downstream half

$\tau_{\ell h} = -\frac{d}{2}$

$\tau_{\ell\ell} = \tau_{hh} = 0$

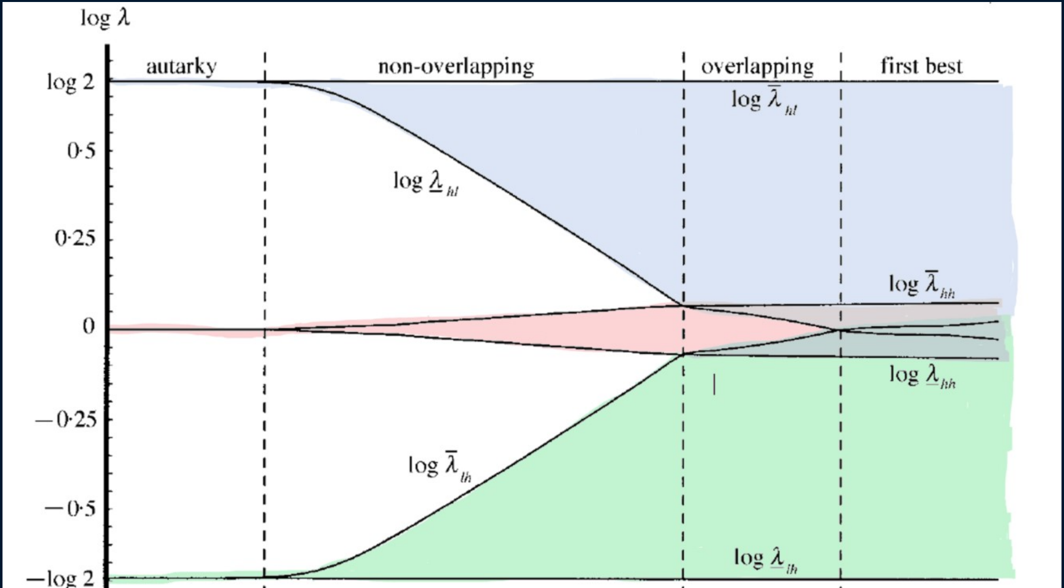
- IID income shocks, no punishments
- Two states y_h, y_ℓ
- Each HH suffers loss d with probability $p \in (0, 1)$
- Identical log preferences $u(c) = v(c) = log(c)$

Because of the log, $[\underline{\lambda}_{hh}, \bar{\lambda}_{hh}] = [\underline{\lambda}_{\ell\ell}, \bar{\lambda}_{\ell\ell}]$

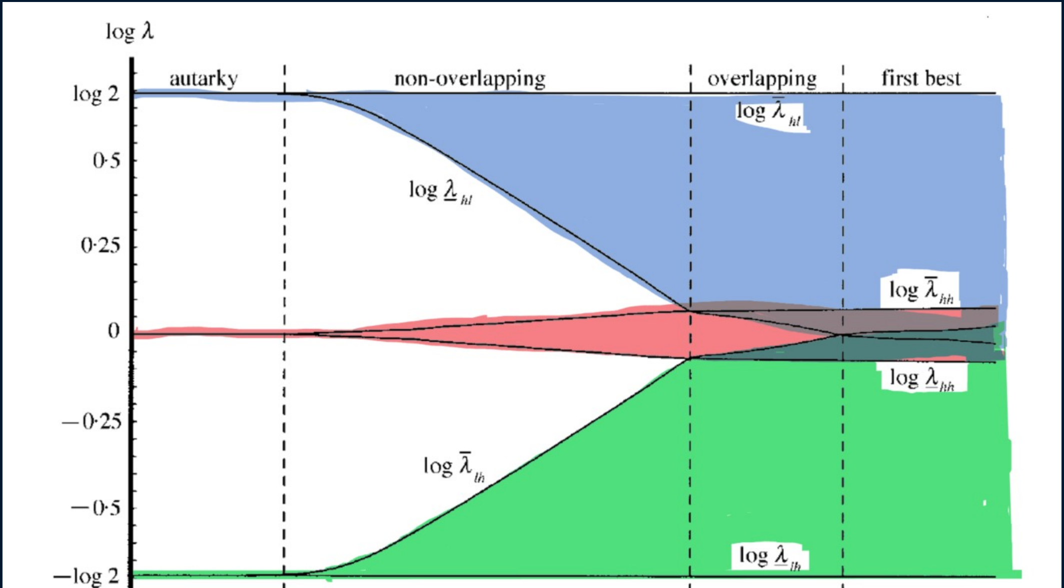
By symmetry:

$$\underline{\lambda}_{h\ell} = \frac{1}{\bar{\lambda}_{\ell h}}$$
$$\underline{\lambda}_{\ell h} = \frac{1}{\bar{\lambda}_{h\ell}}$$
$$\underline{\lambda}_{hh} = \frac{1}{\bar{\lambda}_{hh}}$$

Example: $p = 0.1$, $\frac{d}{y_h} = 0.5$ Main Slides



Example: $p = 0.1$, $\frac{d}{y_h} = 0.5$ Main Slides



1) Suppose we're in $\delta \in (.935, .965)$
2) Upstream gets a bad shock: ℓh
3) $\lambda \to \bar{\lambda}_{\ell h}$, for $1 > \bar{\lambda}_{\ell h} > \xi_{\ell h} = \frac{1}{2}$
4) Downstream transfers $\tau < \frac{d}{2}$ to Upstream s.t. $\frac{v'(c^2)}{u'(c^1)} = \bar{\lambda}_{\ell h}$
5) Updating rule: $\frac{v'(c^2)}{u'(c^1)} = \bar{\lambda}_{\ell h}$ *until* $h\ell$ occurs ($hh, \ell\ell$ Upstream $\to$ Downstream. Why?)
6) At $h\ell$, situation reverses: $\lambda \to \underline{\lambda}_{h\ell}$
7) Like a debt contract that gets repaid until another bad shock hits only one HH

- If both HHs hit, still repay
- If one HH hit, the previous history is forgiven, start fresh

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Professors (occasional): Rohini Pande, Ken Gillingham, Robert Jensen

Ideas: Pam Jakiela, Owen Ozier, Carl Obst

Peers:

Fellowships: SYLFF

DHS contains:

HV101: relationship to household head (use for: do parents live in household)
HV221: whether household has telephone
HV236: person fetching water (only old DHS)
Child Labor Module Variables: worked for someone outside household, hours worked,fetched wood or water (hours); worked for family member (hours); did domestic household work (hours)
V130: religion; V131 Ethnicity (for size of other possible insurance networks?)
V167: number of trips away from home for one or more nights in last 12 months
V740: whether respondent works on own land, family land, rented land, or someone else's land (not core DHS VII anymore)

DHS contains:

HV111: whether mother of household member is still alive (base: children < 18)
HV113: whether father of household member is alive (base: children aged < 18)
H11: whether child had diarrhea in last 24 hours or last 2 weeks

DHS contains:

HV201: main source of drinking water
HV202: main source of water for use other than drinking
HV204: time taken to get water source for drinking water
HV244: owns land usable for agriculture; HV245 hectares for agricultural land

DHS contains:

HV205: type of toilet
HV 20x: whether household has certain durables
HV21x: materials of floors and roofs
HV221: whether household has telephone
HV24x: assets, including most livestock
HV244: owns land usable for agriculture; HV245 hectares for agricultural land
HV270: wealth index
MV484: smoking per week

DHS contains:

V104: nubmer of years living in the village/town/city of being interviewed
V705: partner's occupation groups; V717 respondent's occupation group
MV605: desire for more children; MV613: ideal number of children; MV621 whether partner agrees
MV72x: working, at home or away; worked in the last 12 months; seasonal, occasional, or annual worker
MV740: whether respondent works in own, family, rented or someone else's land (not core DHS VII anymore)
V169: owns mobile telephone (and uses for financial transactions)
V167-168: times away from home for 1 night or more in last 12 months

Ansink, E. and Ruijs, A. (2008). Climate Change and the Stability of Water Allocation Agreements. *Environmental and Resource Economics*, 41(2):249–266.

Burke, M., Hsiang, S. M., and Miguel, E. (2015). Climate and Conflict. *Annual Review of Economics*, 7(1):577–617.

De Stefano, L., Petersen-Perlman, J. D., Sproles, E. A., Eynard, J., and Wolf, A. T. (2017). Assessment of transboundary river basins for potential hydro-political tensions. *Global Environmental Change*, 45:35–46.

Dinar, S., Katz, D., De Stefano, L., and Blankespoor, B. (2019). Do treaties matter? Climate change, water variability, and cooperation along transboundary river basins. *Political Geography*, 69:162–172.

GADM (2022). Database of Global Administrative Areas (GADM) version 4.1.

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., De Chiara, G., Dahlgren, P., Dee, D., Diamantakis, M., Dragani, R., Flemming, J., Forbes, R., Fuentes, M., Geer, A., Haimberger, L., Healy, S., Hogan, R. J., Hólm, E., Janisková, M., Keeley, S., Laloyaux, P., Lopez, P., Lupu, C., Radnoti, G., De Rosnay, P., Rozum, I., Vamborg, F., Villaume, S., and Thépaut, J.-N. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, 146(730):1999–2049.

International Water Management Institute (2024). Irrigation in Africa.

Ligon, E., Thomas, J. P., and Worrall, T. (2002). Informal Insurance Arrangements with Limited Commitment: Theory and Evidence from Village Economies. *The Review of Economic Studies*, 69(1):209–244.

Lipscomb, M. and Mobarak, A. M. (2017). Decentralization and Pollution Spillovers: Evidence from the Re-drawing of County Borders in Brazil. *The Review of Economic Studies*, 84(1):464–502.

Mapunda, D. W., Chen, S. S., and Yu, C. (2018). The role of informal small-scale water supply system in resolving drinking water shortages in peri-urban Dar Es Salaam, Tanzania. *Applied Geography*, 92:112–122.

McGuirk, E. and Nunn, N. (Forthcoming). Transhumant Pastoralism, Climate Change, and Conflict in Africa. *Review of Economic Studies*.

Meghir, C., Mobarak, A. M., Mommaerts, C. D., and Morten, M. (2019). Migration and Informal Insurance: Evidence from a Randomized Controlled Trial and a Structural Model. *National Bureau of Economic Research Working Paper Series*, No. 26082.

Monerie, P.-A., Pohl, B., and Gaetani, M. (2021). The fast response of Sahel precipitation to climate change allows effective mitigation action. *npj Climate and Atmospheric Science*, 4(1):1–8.

Nemarundwe, N. and Kozanayi, W. (2003). Institutional Arrangements for Water Resource Use: A Case Study from Southern Zimbabwe. *Journal of Southern African Studies*, 29(1):193–206.

Persson, T., David, S., and Kudamatsu, M. (2012). Weather and Infant Mortality in Africa. CEPR Discussion Paper 9222, C.E.P.R. Discussion Papers.

ReliefWeb (2020). The Sahel in the midst of climate change.

Ryan, N. and Sudarshan, A. (2022). Rationing the Commons. *Journal of Political Economy*, 130(1):210–257.

Wolf, A. T. (1999). "Water Wars" and Water Reality: Conflict and Cooperation Along International Waterways. In Lonergan, S. C., editor, *Environmental Change, Adaptation, and Security*, NATO ASI Series, pages 251–265. Springer Netherlands, Dordrecht.

Wolf, A. T., Yoffe, S. B., and Giordano, M. (2003). International waters: Identifying basins at risk. *Water Policy*, 5(1):29–60.