The Gravity of Violence

Mathieu Couttenier [1] Julian Marcoux [2] Thierry Mayer [3]
Mathias Thoenig [4]

[1]ENS de Lyon and CEPR

[2]University of Lausanne

[3]Sciences Po, CEPII and CEPR

[4]University of Lausanne, University of Oxford and CEPR

July 11, 2023

Motivation

- Prevalence of conflicts is not going away:
  - 12% of the world population lives in conflict zones in 2010s
  - 35% live in conflict-ridden country, even if distant from violence (Korovkin and Makarin, 2021)
- Violence seems to be a major obstacle to growth and development: 60% of the poorest countries are affected by armed conflict (OECD, 2009)
- Causality runs both ways with important policy implications

  → **Calls for an integrated (dev/violence) analysis**.
- Violence is not purely local:

  → **Calls for a spatial analysis**.

Motivation (cont.)

- Call for a better understanding of conflicts from a GE perspective is not isolated (Dell, Jones & Olken (JEL 2014), Burke, Hsiang & Miguel (AR 2015), ...)

> *"Modeling general equilibrium forces is important as economic shocks that alter the opportunity cost of violence could also affect the spoils of victory or a government's capacity to repel insurgents, yielding an unclear relationship. This ambiguity is reflected in a markedly inconclusive empirical literature, characterized by inconsistent findings and by significant identification challenges: income may affect conflict; conflict may affect income; and both"*
>
> — McGuirk & Burke, JPE 2020

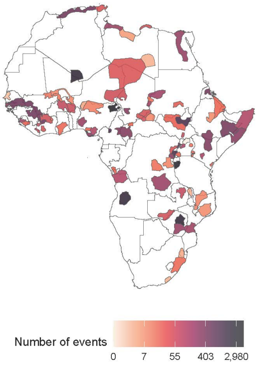
- Quantifying this two-way causation is crucial for policy interventions:
  - Ambiguous impact of road/infrastructure building
  - How should WB design its Great Lakes Trade Facilitation Project?
- The GE model should account for origin and destination of violence:
  - How far does violence travel?
  - Incomes at origin and destination should not have same effect.

"Vectorization" of Violence

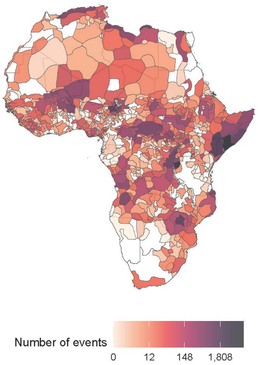
ACLED events

$\Rightarrow$

Origins of violence



Destinations of violence



Our GE Model of Trade and Conflict

- Main challenge: Coupling economic & fighting margins in a tractable and estimable model
- Our approach: build on conceptual/formal similarities in trade, migration & conflict models
  $\Rightarrow$ CES/Logit functional forms governing aggregate behaviors

- What the model does:
  1. Derives and estimates an equation for bilateral flows of violence
  2. Simple inversion procedure to reveal structural parameters
  3. Quantify counterfactual policy interventions
  4. Can be easily combined with Quantitative Spatial Models (location choice and/or migration)
  5. Can be adjusted further to specific contexts

$\Rightarrow$ Today, focus on 1), 2) and first pass at 3).

Section 2

Theory

Setup I – Trade in goods

- N regions indexed by i. Population $\bar{L}_i$ freely allocates between farming (L_i) vs fighting (l_i).
- Farming/trade in goods:
  - ▷ Each region i is the unique source of each variety.
  - ▷ Consumers in n have a CES utility ($\sigma > 1$) over all varieties:

$$U_n = \left(\sum_i (q_{in})^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

  - ▷ Perfect competition + iceberg trade costs τ_{in}: $p_{in} = w_i^P \tau_{in}/A_i$, w_i^P/A_i being wage over productivity of i's workers.
- The share of expenditure that consumers of region n spend on the variety from i is

$$\pi_{in} \equiv \frac{(\tau_{in} w_i^P/A_i)^{1-\sigma}}{\sum_k (\tau_{kn} w_k^P/A_k)^{1-\sigma}} \tag{2}$$

Gravity of goods

- Gravity equation of bilateral trade flows (value) from i to n

$$Y_{in} = \pi_{in} E_n = \tau_{in}^{1-\sigma} \times \left(\frac{w_i^P}{A_i} \right)^{1-\sigma} \times \frac{E_n}{\sum_k \left(\frac{\tau_{kn} w_k^P}{A_k} \right)^{1-\sigma}} \tag{3}$$

- $\exists$ many microfoundations that lead to same aggregate bilateral trade equation (Armington / Anderson and van Wincoop, Krugman, Anderson, De Palma & Thisse, Eaton and Kortum, Melitz/Chaney).
- Aggregate trade revenues of producing region i (incl. internal trade) are given by

$$w_i^P \times L_i = \sum_n \pi_{in} E_n, \tag{4}$$

with E_n total expenditure value in n.

Setup II – Fighting: Violence as Appropriation

We model an appropriation game ▸ Details

- Destination n:
  - ▷ Unsecured share $(1 - s_n)$ of total income Y_n looted by fighting groups
  - ▷ $0 < s_n < 1$ is *exogenous* state capacity
- Origin i:
  - ▷ Hosts one fighting group that recruits l_i fighters at local wage w_i^F
  - ▷ **Optimal assignment of fighters** l_{in} to loot $(1 - s_n)Y_n$ subject to a spatial friction $\xi_{in} \geq 1$
- On battlefield of n, each fighting group i
  - ▷ "Produces" violence with CRS technology $\texttt{violence}_{in} = \psi_i l_{in}$
  - ▷ Has operational performance $(\texttt{violence}_{in}/\xi_{in}) \times \tilde{u}_{in}$
  - ▷ $\tilde{u}_{in} \sim$ Frechet(γ) (military capacity vs "luck")

Setup III – Farming vs Fighting

- Victory in n goes to the group with largest operational performance. Success probability:

$$p_{in} \equiv \mathbb{P}\left(\frac{\psi_i l_{in}\tilde{u}_{in}}{\xi_{in}} > \frac{\psi_k l_{kn}\tilde{u}_{kn}}{\xi_{kn}}, \quad \forall k \neq i\right) = \frac{(\psi_i l_{in}/\xi_{in})^\gamma}{\sum_k (\psi_k l_{kn}/\xi_{kn})^\gamma} \tag{5}$$

- New: p_{in} (equivalent of market share in trade) is a CES of **endogenous** bilateral effort exerted l_{in}.
- Optimal l_{in} maximize gross fighting revenues:

$$R_i \equiv \max_{\{l_{in}\}} \sum_n p_{in} \times (1 - s_n) Y_n, \quad \text{s.t.} \quad l_i = \sum_n l_{in} \tag{6}$$

- Assume i) atomistic players and ii) $\gamma < 1$ to ensure interior solution
- Gross income of fighters in region i:

$$w_i^F \times l_i = R_i \tag{7}$$

Gravity of violence

- Optimal allocation of troops yields equilibrium flow of violence from i to n

$$\texttt{violence}_{in} \equiv \psi_i l_{in} = \xi_{in}^{-\frac{\gamma}{1-\gamma}} \times \left(\frac{\psi_i}{w_i^F}\right)^{\frac{1}{1-\gamma}} \times \frac{(1-s_n)Y_n}{\sum_k \xi_{kn}^{-\frac{\gamma}{1-\gamma}} \left(\frac{\psi_k}{w_k^F}\right)^{\frac{\gamma}{1-\gamma}}} \tag{8}$$

- Resembles **(quantity) gravity equations from a large class of trade/migration models**
- Economic shocks impact violence in complex ways: The full spatial dispersion of wages matters
  - Opportunity Cost: $w_i^F \uparrow$, $\texttt{violence}_{in} \downarrow$
  - Rapacity effect: $w_n^P \uparrow$, $Y_n \uparrow$, $\texttt{violence}_{in} \uparrow$
  - State capacity: $\frac{\partial \texttt{violence}_{in}}{\partial s_n} \times \frac{\partial s_n}{\partial w_n} = 0$ in our baseline setup (exogenous s_n)
  - Multilateral Resistance of Violence (new effect!): $w_{k\neq i}^F \uparrow$, competition on battlefield $n \downarrow$, $\texttt{violence}_{in} \uparrow$
- Classical regressions of violence in n are mis-specified. ▸ Monadic vs Dyadic regressions

General Equilibrium Closure

- Free Occupation Choice Farming/Fighting: equalization of (fully secured) incomes

$$s_i w_i^P = s_i w_i^F = s_i w_i \tag{9}$$

- Gross Nominal Income:

$$Y_i = w_i^P L_i + w_i^F l_i = w_i \bar{L}_i \tag{10}$$

- Labor Market Clearing

$$\bar{L}_i = L_i + l_i \tag{11}$$

General Equilibrium: Characterization

- Farming (and Trade) revenues:

$$w_i L_i = \sum_n \frac{\tau_{in}^{-(\sigma-1)} \left(\frac{A_i}{w_i}\right)^{\sigma-1}}{\sum_k \tau_{kn}^{-(\sigma-1)} \left(\frac{A_k}{w_k}\right)^{\sigma-1}} s_n w_n \bar{L}_n \tag{12}$$

- Fighting revenues:

$$w_i l_i = \sum_n w_i l_{in} = \sum_n \frac{\xi_{in}^{-\frac{\gamma}{1-\gamma}} \left(\frac{\psi_i}{w_i}\right)^{\frac{\gamma}{1-\gamma}}}{\sum_k \xi_{kn}^{-\frac{\gamma}{1-\gamma}} \left(\frac{\psi_k}{w_k}\right)^{\frac{\gamma}{1-\gamma}}} (1-s_n) w_n \bar{L}_n \tag{13}$$

- Labor Market Clearing:

$$\bar{L}_i = L_i + l_i \tag{14}$$

General Equilibrium: Existence and Uniqueness

- Fighting and Trade revenues are isomorphic

  ⇒ We can use techniques from trade/spatial economics.

  ⇒ Combining fighting and trade yields a (fixed point) "master equation" system

$$w_i \bar{L}_i = \sum_n \beta_{in}(\mathbf{w}) w_n \bar{L}_n \tag{15}$$

where $\beta_{in}(.)$ are non-linear functions of the wage vector $\mathbf{w}$

$$\beta_{in}(\mathbf{w}) \equiv (1 - s_n) \times \frac{w_i^{-\frac{\gamma}{1-\gamma}} \left(\frac{\psi_i}{\xi_{in}}\right)^{\frac{\gamma}{1-\gamma}}}{\sum_k \left(\frac{\psi_k}{\xi_{kn} w_k}\right)^{\frac{\gamma}{1-\gamma}}} + s_n \times \frac{w_i^{1-\sigma} \left(\frac{A_i}{\tau_{in}}\right)^{\sigma-1}}{\sum_k \left(\frac{A_k}{\tau_{kn} w_k}\right)^{\sigma-1}} \tag{16}$$

- Existence and uniqueness of GE: follows from Alvarez and Lucas (2007) and Mas-Colell, Whinston and Green (1995)

Section 3

Empirical Gravity of Violence

Econometric specification

- Theory predicts a log-linear gravity equation of violence:

$$\frac{\texttt{violence}_{int}}{\texttt{violence}_{nt}} = \frac{\psi_{it} l_{int}}{\sum_k \psi_{kt} l_{knt}} = \xi_{in}^{-\frac{\gamma}{1-\gamma}} \times \left(\frac{\psi_{it}}{w_{it}}\right)^{\frac{1}{1-\gamma}} \times \left[\sum_k \xi_{kn}^{-\frac{\gamma}{1-\gamma}} \left(\frac{\psi_{kt}}{w_{kt}}\right)^{\frac{1}{1-\gamma}}\right]^{-1} \tag{17}$$

- Methods from the gravity world:
  - ▷ High Dimensional FE: Origin$\times t$ and Destination$\times t$ FEs
  - ▷ PPML natural estimator (theory-consistent + structural interpretation of FEs + zeroes)

$$\mathbb{E}\left(\frac{\texttt{violence}_{int}}{\texttt{violence}_{nt}}\right) = \exp\left\{-\frac{\gamma}{1-\gamma}\log \xi_{in} + \texttt{FE}^{o}_{it} + \texttt{FE}^{d}_{nt}\right\} \tag{18}$$

Construction $\texttt{violence}_{int}$: Raw data

- ACLED: geolocalized GPS events, all Africa, 1997-2022, with actors involved in each event:

Type of actors	% Events	% Groups	% Obs.
Rebel groups	24.6	5.4	14.4
Political Militias	25.2	20.2	15.2
State Forces	36.5	13	21.8
Identity Militias	8.4	55.9	6.2
Rioters	11	.9	6.9
Protesters	23.8	1	13.7
Civilians	32.7	1.4	18.9
External/Other Forces	4.8	4.9	2.8

$\Rightarrow$ We keep rebel groups and political militias (about 50% events)

Examples #1: Rebels vs Civilians

- Example #1a: DRC

Event id.	Actors	Date	Nature violence	Location	Lat./Long.
DRC9785	LRA: Lords Resistance Army	30/12/2015	Violence ag. civilians	Ebale	4.0678;26.6292
DRC9785	Civilians (DRC)	30/12/2015	Violence ag. civilians	Ebale	4.0678;26.6292

Note: "LRA rebels attacked the Ebale area, looting property and kidnapping 12 people.".

- Example #1b: Central African Republic

Event id.	Actors	Date	Nature violence	Location	Lat./Long.
CEN2885	LRA: Lords Resistance Army	6/07/2015	Violence ag. civilians	Yalinga	6.5081;23.2598
CEN2885	Civilians (Central African Republic)	6/07/2015	Violence ag. civilians	Yalinga	6.5081;23.2598

Note: "LRA attacks Aza, Gbodjo, Malatcha, Ngoudka and Bangana localities of Yalinga in the course of one week between 4-10 July, assaulting and abducting civilians, as well as looting and burning properties".

$\Rightarrow$ In both cases, we keep one observation – LRA: Lords Resistance Army

Examples #2: Rebels vs Rebels

- Example #2a: Mali

Event id.	Actors	Date	Nature violence	Location	Lat./Long.
MLI1141	Ansar Dine	25/12/2015	Battles	Kidal	18.44;1.41
MLI1141	CMA: Coord. of Mov. Azawad	25/12/2015	Battles	Kidal	18.44;1.41

Note: "Ansar Dine ambushed a Tuareg separatist vehicle, killing four".

- Example #2b: Chad

Event id.	Actors	Date	Nature violence	Location	Lat./Long.
CHA333	RAFD: Rally of Democratic Forces	31/01/2007	Battles	Djimeze	11.33;15.33
CHA333	FUC: United Front for Change	31/01/2007	Battles	Djimeze	11.33;15.33

Note: "30 people have died and dozens injured in clashes between ethnic Tama and Zaghawa, FUC and RaFD forces respectively".

⇒ In both cases, we keep two observations.

From Raw Data to Final Sample

Steps	# Events	# Groups	# Obs.
0.Raw	281311	6878	487168
1- Rebels groups + pol. militias	137518	1751	144347
2a- Geographic filter #1	132673	1681	139192
2b- Geographic filter #2	93137	1458	97730
3- Duplicates	92880	1458	96616
4- Drop Sub-events: Other & Sub-events	91853	1409	95533
5a- Name filter #1	91853	1391	97882
5b- Name filter #2	63151	1335	68439

62,577 ACLED events, 373 fighting groups, 1997-2022

- Need to find an “origin” for those events.
- Locate the rear-base of each group
- Not well documented in ACLED
- Collect info for 373 groups: at least to 3 events and fight at least over 3 years.
- Represent a vast majority of violence: 62,577 events
- What is a rear-base on which we can obtain spatial information?

Vectorization of Conflict Events: $\texttt{violence}_{int}$

- Step 1: Choose spatial and temporal units

Geographies
◇ Cells of 0.5×0.5 degree
◇ Admin-2 regions
◇ Ethnic regions (Murdock)

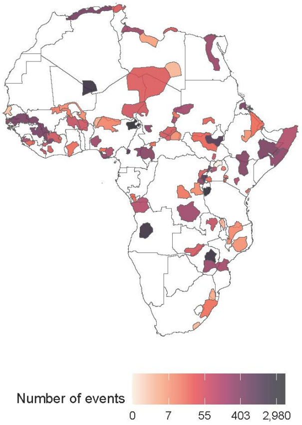
Temporal Units over 1997-2022
◇ Yearly
◇ Every 5 years
◇ Cross-section (sum over years)

- Step 2: Geo-Locate rear base of each group ⇒ Hand-collected information matched 182 armed groups to a rear base $rb(g)$ belonging to 81 ethnic homelands (i)
  → This step reduces the number of events to 28,944 (collection effort ongoing).
- Step 3: Process events into bilateral flows of violence:

$$\texttt{violence}_{in} = \sum_g \mathbb{I}_{rb(g)\in i} \quad \times \quad \sum_t \underbrace{\#\texttt{events}_{gnt}}_{\text{data}}$$

$\texttt{violence}_{in}$: Cross-section of 824 ethnic regions, 1997-2022

81 Origins of violence



486 Destinations of violence

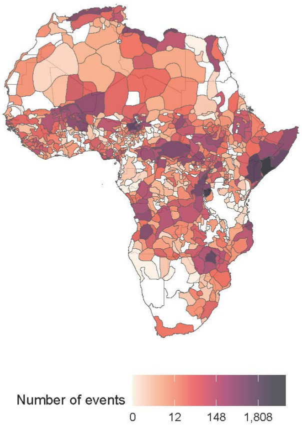
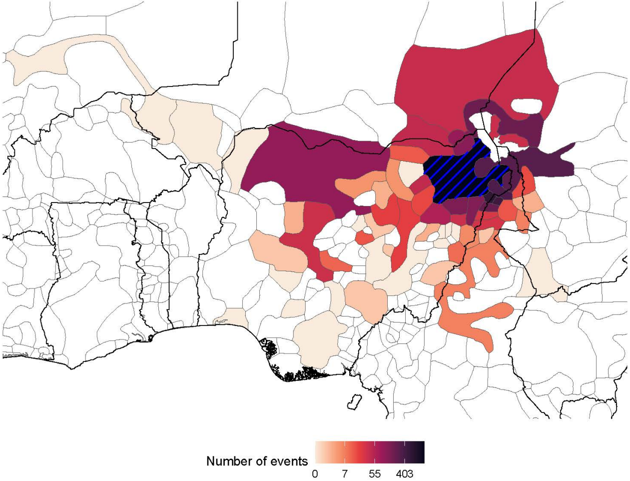


Illustration: Boko Haram & bilateral flows of violence

Kanuri ethnic group



1997-2022; 4,735 events; internal (32%), external (68%)

Econometric Specification - Recap

- Empirical Gravity of Violence — We consider 3 Frictions:
  - ▷ Bilateral distance
  - ▷ Ethnic Homeland Border
  - ▷ Country Border

$$\log \xi_{in} = \alpha_1 \log \mathtt{dist}_{in} + \alpha_2 \mathtt{ethnic}_{in} + \alpha_3 \mathtt{border}_{in} + \nu_{in}$$

- HDFE PPML, cluster dyad, i: origin; n: destination; t: temporal unit

$$\mathbb{E}\left(\frac{\mathtt{violence}_{in}}{\mathtt{violence}_{n}}\right) = \exp\left[-\frac{\alpha_1\gamma}{1-\gamma}\log \mathtt{dist}_{in} - \frac{\alpha_2\gamma}{1-\gamma}\mathtt{ethnic}_{in} - \frac{\alpha_3\gamma}{1-\gamma}\mathtt{border}_{in} + \tilde{\nu}_{in} + \mathtt{FE}_i^o + \mathtt{FE}_n^d\right] \quad (19)$$

- Sample: Cross-section of 81 origins $\times$ 486 destinations $=$ 39366 dyads (note: 97% of zeroes)

Effect of distance

	(1)	(2)	(3)	(4)
Dep. Var. : share of events				
Model: PPML				
(log-)distance	-2.840^{***}	-3.107^{***}	-2.700^{***}	-2.679^{***}
	(0.069)	(0.074)	(0.077)	(0.077)
Ethnic border		2.277^{***}	2.353^{***}	2.271^{***}
		(0.260)	(0.263)	(0.268)
Pol. border			-1.399^{***}	-1.765^{***}
			(0.150)	(0.248)
Pol. border $\times$ one split				0.480^{*}
				(0.267)
Pol. border $\times$ $\geq$2 splits				0.732^{**}
				(0.351)
Observations	39,366	39,366	39,366	39,366

Quantitative interpretation of elasticity = -2.84

- Doubling distance: 76% drop in violence
- Meta-analysis for trade ≈ -1.1 (Head & Mayer, 2014)
- Elasticity of trade by Ground (Trucks in advanced economies) ≈ -2
- **Logistics of violence in Africa = (bad) Roads and Trucks**?

Effect of borders

	(1)	(2)	(3)	(4)
Dep. Var. : share of events Model: PPML				
(log-)distance	-2.840^{***}	-3.107^{***}	-2.700^{***}	-2.679^{***}
	(0.069)	(0.074)	(0.077)	(0.077)
Ethnic border		2.277^{***}	2.353^{***}	2.271^{***}
		(0.260)	(0.263)	(0.268)
Pol. border			-1.399^{***}	-1.765^{***}
			(0.150)	(0.248)
Pol. border $\times$ one split				0.480^{*}
				(0.267)
Pol. border $\times$ $\geq$2 splits				0.732^{**}
				(0.351)
Observations	39,366	39,366	39,366	39,366

Quantitative interpretation (col. 4)

- Crossing Ethnic Border (**Raiding**) : 10-fold increase in violence (col 2)
- Crossing Political Border: 83% drop in violence (col 4, row 3)
- Crossing Political Border when origin is multi-split: 42% drop in violence

Section 4

From Estimation to Counterfactuals

Estimation/Inversion Procedure

1. Estimate gravity of violence (eq. 19) to recover friction elasticities $\widehat{\frac{\alpha\gamma}{1-\gamma}}$ + origin effects $\widehat{\texttt{FE}}_i^o$
2. 2SLS estimation to recover $\widehat{\gamma}$ and $\widehat{\psi}_i$ for all $i \neq 1$

$$\widehat{\texttt{FE}}_i^o = -\frac{1}{1-\gamma}\log\left(\frac{w_i}{w_1}\right) + \underbrace{\frac{1}{1-\gamma}\log\left(\frac{\psi_i}{\psi_1}\right)}_{\equiv \text{residual}}$$

- ◇ Wages are unobservable → proxy with nighttime lights per cap.: $\log\left(\frac{w_i}{w_1}\right) = \lambda \times \log\left(\frac{\texttt{light}_i}{\texttt{light}_1}\right)$

$$\widehat{\texttt{FE}}_i^o = -\frac{\lambda}{1-\gamma}\log\left(\frac{\texttt{light}_i}{\texttt{light}_1}\right) + \text{residual}_i$$

- ◇ 2SLS regression: IV = Average world prices of most suitable crops.
- ◇ Set $\lambda = 0.27$ from Bruederle & Hodler 2018
  → The 2SLS coefficient implies $\hat{\gamma} = 0.69$.
- ◇ Ref. = Zhagawa group (Sudan-Tchad). Ext. sources: $\psi_1 = \text{violence}_1/\text{soldiers}_1 = 206/35000$
  → Recover ψ_i from residual_i

Estimation/Inversion Procedure

3. Sum of revenues captured by i fighters in n adds up to lost income of n:

$$(1 - s_n) w_n \bar{L}_n = \sum_i w_i l_{in} \quad \Rightarrow \quad \hat{s}_n = 1 - \frac{\sum_i (\texttt{light}_i)^\lambda \frac{\texttt{violence}_{in}}{\widehat{\psi}_i}}{(\texttt{light}_n)^\lambda \, \texttt{pop}_n}$$

Sanity checks:

- All $\hat{s}_n$ are in the $(0,1)$ range
- Compare $\hat{s}_n$ against external informational source on local state capacity from Agneman *et al.* (2022)
- Internal consistency: strong correlation between s_n and $\#$ of events in n.

4. Recover the number of farmers/fighters

$$\widehat{l}_i = \frac{\texttt{violence}_i}{\widehat{\psi}_i} \quad \text{and} \quad \widehat{L}_i = \texttt{pop}_i - \widehat{l}_i$$

Sanity checks:

- Realistic share of fighters $\widehat{l}_i / \texttt{pop}_i$: median $= 0.04$, sd $= 0.08$
- We have $\widehat{L}_i > 0$ in all regions

Estimation/Inversion Procedure

5. From Head & Mayer (2014): set $\tau_{in} = \texttt{dis}_{in}^{1.1/4} \times (1 + 0.6 \times \text{border}_{in})$.
6. Numerically invert the goods market clearing equation to recover $\widehat{A}_i$:

$$A_i^{1-\sigma} = \sum_n \frac{\tau_{in}^{-(\sigma-1)} (\texttt{light}_i)^{\lambda\times(1-\sigma)}}{\sum_k \tau_{kn}^{-(\sigma-1)} A_k^{\sigma-1} (\texttt{light}_k)^{\lambda\times(1-\sigma)}} \widehat{s}_n \left(\frac{\texttt{light}_n}{\texttt{light}_i}\right)^{\lambda} \frac{\texttt{pop}_n}{\widehat{L}_i} \tag{20}$$

Fixed point iteration:

1: Start with a vector of A_i obtained from previous iterations (Initial conditions = nighttime light)
2: Compute the RHS of the equation
3: LHS of the equation yields a new vector A_i'
4: Use a dampening factor δ to compute the new vector of productivity as $\delta \times A_i + (1-\delta) \times A_i'$
5: Iterate until it converges

Sanity check: strong correlation A_i and nighttime light

Section 5

Counterfactual Simulations

Counterfactual Simulations: Method I

- We simulate (i) the factual equilibrium, (ii) the counterfactual equilibrium and (iii) percentage changes in all relevant outcomes (EHA not doable since we do not observe π_{in}).

- Simulation Method = Nested Iterative Fixed Point Procedure
- Wage (inner) loop: Fixed point of $\mathbf{w}$ given set $\Theta = \{\gamma, \sigma, s_n, \psi_i, \mathtt{pop}_i, A_i, \tau_{in}, \xi_{in}\}$:

$$w_i = \sum_n \beta_{in}(\mathbf{w}) w_n \frac{\mathtt{pop}_n}{\mathtt{pop}_i}, \tag{21}$$

  where $\beta_{in}(.)$ are non-linear functions of $\mathbf{w}$ given by (16).

- Outcomes: Trade (Y_{in}), $\mathtt{violence}_{in}$, Income (Y_n), Expenditure ($E_n = s_n Y_n$), Welfare ($\omega_n = \frac{s_n w_n}{P_n}$).

Counterfactual Simulations: Method II

- Unrealistic to hold **A** constant $\rightarrow$ Augment model with destruction spillovers:

$$A_n = \bar{A}_n \exp\{-\varepsilon \times \texttt{violence}_n\,[\mathbf{w}(\mathbf{A})]\} \tag{22}$$

- Solving for **w** is not sufficient anymore, since affects **A**.
- Calibration of ε:
  - ◇ Within model, the semi-elasticity of TFP to violence $\varepsilon = 0.0075$
  - ◇ One additional ACLED event decreases productivity by 0.75%
  - ◇ $\bar{A}_n$: recovered from inverting (22) using estimated A_n, observed $\texttt{violence}_n$ and calibrated ε.
- Productivity (outer) loop:

  1: Use w_i from inner loop, compute RHS of (22). LHS of (22) yields A'_n.
  2: Use a dampening factor δ to compute the new vector of TFP as $\delta \times A_n + (1-\delta) \times A'_n$.

  Overall simulation procedure stops when **A** stops changing..

Counterfactual Simulations: Welfare changes in the model

- Do we have some kind of Arkolakis et al. (2012) formula for change in welfare ($\omega_n = \frac{s_n w_n}{P_n}$)?
- Self trade share:

$$\pi_{nn} = (\tau_{nn} w_n / A_n)^{1-\sigma} P_n^{\sigma-1} \rightarrow \frac{w_n}{P_n} = \pi_{nn}^{\frac{1}{1-\sigma}} \frac{A_n}{\tau_{nn}}$$

- Assume that τ_{nn}, s_n and $\bar{A}_n$ are unaffected by CF:

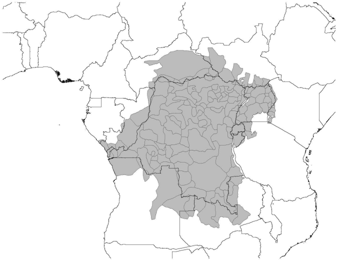
$$\frac{\omega_n'}{\omega_n} = \left(\frac{\pi_{nn}'}{\pi_{nn}}\right)^{\frac{1}{1-\sigma}} \frac{A_n'}{A_n} = \left(\frac{\pi_{nn}'}{\pi_{nn}}\right)^{\frac{1}{1-\sigma}} \exp\{-\varepsilon(\mathtt{violence}_n' - \mathtt{violence}_n)\}.$$

- First term is traditional ACR formula (with indirect influence of violence through trade).
- Second term is an additional term accounting for destruction spillovers.

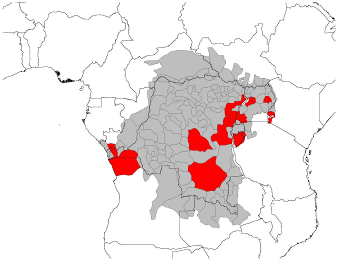
World Bank Great Lakes Initiative (GLI)

- Dual objective: Achieving development and peace in the GLR (Great Lakes Region)
  - ◇ GLR = 131 ethnic regions $\in$ { RDC, Rwanda, Uganda } out of 824 regions in Africa
  - ◇ 32% of all violence in Africa over 1997-2022
  - ◇ 14 attacking ethnic regions in GLR; 69 attacked ethnic regions

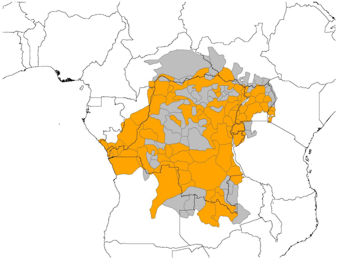
Location of ethnic groups



14 Origins of violence



69 Destinations of violence



Border Crossing Facilitation

- Calibration from trade lit.: $\sigma = 5$, Gravity coef.. of border effect ≈ -1.88.
- Gravity Estimates of violence: $\gamma \approx 0.69$ with coef.. of border effect $\approx$ -1.399
- Counterfactual scenario: Halving the Ad Valorem Equivalents of RDC-RWA-UGA borders crossing for trade frictions (60%) and fighting frictions (87%)

$$\tau_{in} = \texttt{dist}_{in}^{1.1/4} \times (1 + 0.6 \times \text{border}_{in}) \quad \rightarrow \quad \tau'_{in} = \texttt{dist}_{in}^{1.1/4} \times (1 + 0.3 \times \text{border}_{in}) \tag{23}$$

$$\xi_{in} = \text{dist}_{in}^{\alpha_1} \times (1 + 0.87 \times \text{border}_{in}) \quad \rightarrow \quad \xi'_{in} = \text{dist}_{in}^{\alpha_1} \times (1 + 0.435 \times \text{border}_{in}) \tag{24}$$

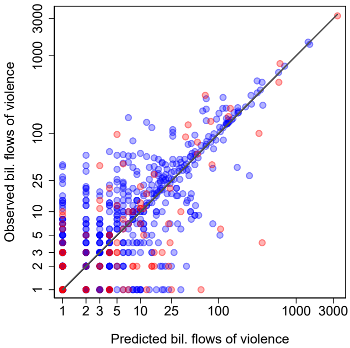
- Pre- vs Post- intervention border effects:
  - Fighting reduced by 75% (pre) vs 55% (post)
  - Trade reduced by 85% (pre) to 65% (post)

Initial equilibrium: some statistics

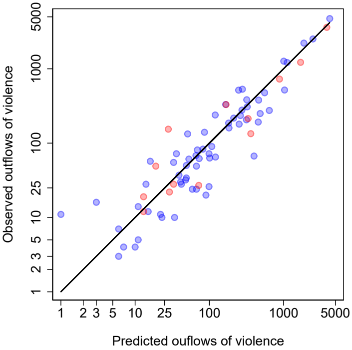
	Avg. % violence		Average percent imports			
Origin:	GLR	RoA	All Groups	Foreign Groups	GLR	RoA
<u>Destination:</u>						
GLR	60.15	39.85	84.55	22.93	61.3	23.25
RoA	1.99	98.01	82.8	22.89	6.27	76.53

Note: Numbers represent average percentage points. GLR = Great Lakes Region, and RoA = Rest of Africa.

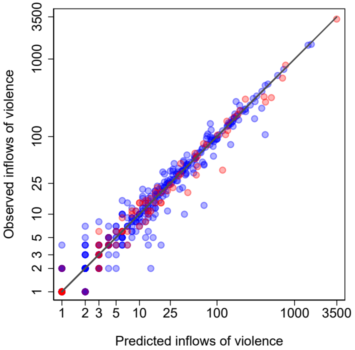
Goodness of fit



(a) Bilateral



(b) Outward



(c) Inward

Border-crossing Facilitation: Aggregate Results

% Change in :		Agg Violence	Avg violence			Avg trade share			Average	
			All	GLR	RoA	Self	GLR	RoA	TFP	Welfare
Model	Region									
Pure Trade	GLR	0	0	0	0	-8.55	9.22	-4.64	0	2.29
	RoA	0	0	0	0	.35	-4.25	.32	0	-.09
Damage-free	GLR	.1	1.14	16.05	-8.33	-8.55	9.22	-4.63	0	2.29
	RoA	-.13	-.08	-3.88	0	.35	-4.26	.32	0	-.09
Damage-inclusive	GLR	-1.01	-1.06	8.56	-3.88	-8.76	9.24	-4.88	.4	2.76
	RoA	-.09	-.21	-16.97	.2	.29	-3.69	.29	.01	-.06

Note: Numbers represent average percent changes. GLR = Great Lakes Region, and RoA = Rest of Africa

- Damage-free: GLR $\rightarrow$ GLR violence $\uparrow$ 16%. Partly compensated by $\downarrow$ 8% RoA $\rightarrow$ GLR (MRV).
- Damage-inclusive: GLR $\rightarrow$ GLR violence $\uparrow$ 8.5%. Now more than compensated by $\downarrow$ 4% RoA $\rightarrow$ GLR. Overall fall in violence, and rise in TFP and welfare.

Decomposition of violence effects

- Impact on violence can be decomposed as:

$$\Delta \log \texttt{violence}_{in} = -\frac{\gamma}{1-\gamma}\Delta \log \xi_{in} - \frac{1}{1-\gamma}\Delta \log w_i + \Delta \log w_n - \Delta \log \mathrm{MRV}_n$$

  - ◇ Direct effect of fighting friction
  - ◇ Trade-induced differential in wages
  - ◇ Multilateral Resistance of Violence

⇒ Net effect on violence depends on the full spatial structure

Damage-free CF level of violence: decomposition of 16% increase

i and n are		#	Base	Average Δ log				
in diff. countries	$\neq$	dyads	$\texttt{violence}_{in}$	$\texttt{violence}_{in}$	$\xi_{in}^{-\frac{\gamma}{1-\gamma}}$	$w_i^{-\frac{1}{1-\gamma}}$	w_n	MRV_n^{-1}
0	0	13	336.9	-.097	0	-.037	.011	-.071
0	1	414	5.1	-.101	0	-.033	.009	-.076
1	1	777	.9	.448	.592	-.037	.013	-.12

Note: Numbers represent average percentage point changes for the ethnic groups considered as destinations of either violence or trade (n). GLR = Great Lakes Region, and RoA = Rest of Africa

- ◇ Differential in wages reduces violence for all dyads
- ◇ MRV reduces violence for all dyads
- ◇ Direct effect of fighting friction raises violence

Initial count of events is very low in 3rd line, but large impact of frictions brings the overall increase of violence to 16%.

Conclusion

We build and estimate a Quantitative Spatial Model of Trade and Conflict

- ▷ Structural estimation is simple, portable and frugal in terms of data requirement
- ▷ Gravity forces at work... for violence too
- ▷ Large effects of spatial frictions on violence (distance, border)
- ▷ GE feedback loops between fighting and economic equilibria are quantitatively important
- ▷ Counterfactual simulations inform policies that pursue the dual objective of development and peace
- ▷ Generic framework that can be adjusted further to specific contexts

Appendix

Appropriation Game I

Sequence of the appropriation game:

1. Front-loaded payment of Y_n^P to producers. Share s_n is immediately (and definitively) secured.
2. "Once-for-all" optimal assignment of fighters l_{in} from region i to region n
3. Sub-period 1: Fighters in i loot unsecured farmers' income: $R_i(1) = \sum_n p_{in} \times (1 - s_n) Y_n^P$.
4. Stage Game at sub-period $k > 1$:
   - i/ Looting by fighters l_{in} of income still unsecured in n.
   - ii/ $R_i(k)$ is (friction-free) repatriated in i.
   - iii/ A share s_i of $R_i(k)$ is *definitively* secured. Residual income $(1 - s_i)R_i(k)$ is unsecured.
   - iv/ If $(1 - s_i)R_i(k) < \varepsilon$ for all i, sub-game ends, we move to stage 5 (below). Otherwise, proceed to sub-period $(k + 1)$ and restart (i) to (iii).
5. Fighting revenues repatriated in i; production, trade & consumption take place.

- Farmers are looted by fighters, who are looted by fighters, who are looted by fighters...
  $\rightarrow$ Need a detailed accounting of looted resources

Appropriation Game II (follow the money)

- l.o.m of appropriation in matrix notation

$$\mathbf{R}(1) = \mathbf{A}\mathbf{Y}^{\mathbf{P}}, \quad \text{and} \quad \mathbf{R}(k) = \mathbf{A}\mathbf{R}(k-1) \text{ for } \quad k > 1, \tag{25}$$

  where $\mathbf{A}$ is the $(N \times N)$ appropriation matrix: $a_{in} = p_{in} \times (1 - s_n)$
- End game: Asymptotically, $\mathbf{R}(k) = \mathbf{A}^k\mathbf{Y}^{\mathbf{P}} \to 0$
- Gross fighting revenues accumulated over the entire game:

$$\mathbf{R} = \sum_{k=1}^{\infty} \mathbf{R}(k) = \sum_{k=1}^{\infty} \mathbf{A}^k\mathbf{Y}^{\mathbf{P}} = \mathbf{A}\left(\mathbf{Y}^{\mathbf{P}} + \sum_{k=1}^{\infty} \mathbf{A}^k\mathbf{Y}^{\mathbf{P}}\right) = \mathbf{A}\left(\mathbf{Y}^{\mathbf{P}} + \mathbf{R}\right) = \mathbf{A}\mathbf{Y}, \tag{26}$$

  where $\mathbf{Y}$ is the vector of total gross incomes.
- Gross fighting revenues accruing to region i

$$R_i = \sum_n p_{in} \times (1 - s_n) Y_n$$

Appropriation Game III: From gross income to expenditure

- Only secured part of revenues is effectively spent by producers and fighters. Rest is looted.
- Gross aggregate income: $Y_i = Y_i^P + R_i$.
- Expenditure of producers: $E_i^P = s_i Y_i^P$.
- At stage k, only share s_i of fighters' flow of revenues is secured. Expenditure of fighters:

$$E_i^F = \sum_{k=1}^{\infty} s_i R_i(k) = s_i \sum_{k=1}^{\infty} R_i(k) = s_i R_i$$

- Total expenditure of region i:

$$E_i = E_i^P + E_i^F = s_i \left(Y_i^P + R_i \right) = s_i Y_i$$

- E_i / Y_i is not affected by the (endog.) farming/fighting composition $\rightarrow$ **very useful** (but not vital) for the GE analysis: symmetry in the agg. trade and fighting revenue equations.

back

Fighting : link with monadic conflict regressions

- A (large) literature looks at determinants of $\texttt{violence}_{nt}$.
- Equation (8) informs us on potential misspecification of monadic regressions:

$$\log \texttt{violence}_{nt} \equiv \log \sum_i \texttt{violence}_{int} = \beta \times \log w_{nt} + \texttt{FE}_n + \texttt{FE}_t + \varepsilon_{nt} \tag{27}$$

▷ Is it origin (w_{it}) or destination (w_{nt}) violence determinants?
↪ w_{nt} is a shifter of income at destination (e.g. mineral prices, fertilizer, temperature shock).

▷ If destination, $\texttt{FE}_n$ captures (log of) $\frac{(1-s_n)Y_n}{\Phi_n}$ with multilateral resistance term $\Phi_n \equiv \sum_k \xi_{kn}^{-\frac{\gamma}{1-\gamma}} \left(\frac{\psi_k}{w_k}\right)^{\frac{\gamma}{1-\gamma}}$.
↪ Implicitly assumes that $\frac{(1-s_n)Y_n}{\Phi_n}$ is constant over time.

▷ Error term ε_{nt} captures $\sum_i \xi_{int}^{-\frac{\gamma}{1-\gamma}} \left(\frac{\psi_{it}}{w_{it}}\right)^{\frac{1}{1-\gamma}}$, with potential correlation with w_{nt}.

back to GoV

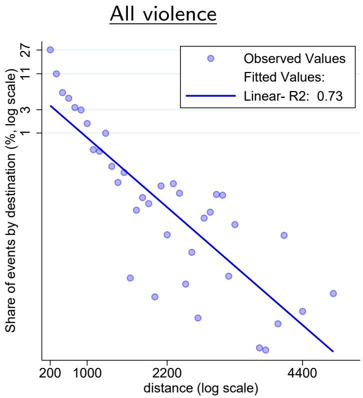
Type of events

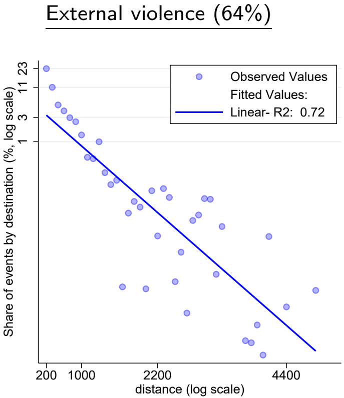
▸ back to data

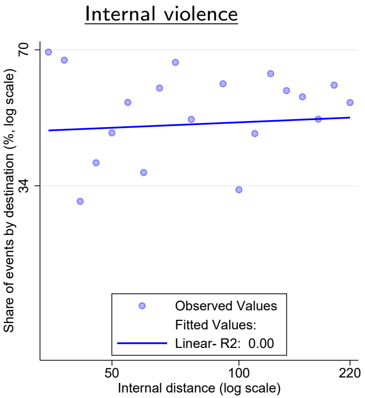
Steps	Step 0-Raw	Step 5b- Name filter #2
Type of violence	% obs	% obs
Battles	30	54.2
Explosions/Remote violence	8.5	10.2
Protests	15.6	.2
Riots	11	.3
Strategic developments	6.4	7.9
Violence against civilians	28.5	27.2

Note: ACLED categorizes events into the following types: *Battles* correspond to violent confrontations between two politically organized armed groups; *Explosions/Remote Violence* refer to events involving one-sided acts of violence where the aggressor uses tools or tactics that prevent the targeted group from effectively responding; *Protests* are nonviolent public demonstrations where participants may face violence from others; *Riots* correspond to events involving acts of violence and disruption carried out by demonstrators or mobs; *Strategic Developments* encompasse events that may not directly involve political violence, but they can potentially trigger future violent events; *Violence Against Civilians* refer to deliberate acts of violence inflicted by organized armed groups upon unarmed non-combatants.

Distance effects (unconditional binscatters)

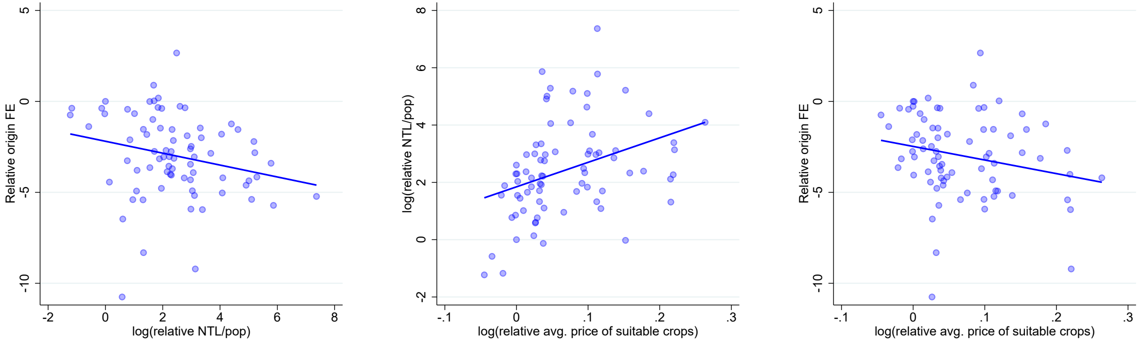






Violence origin FE and wages (step 2)

- Wages w_i are unobservable $\rightarrow$ proxy with Night Time Lights per capita.
- Then instrument proxy of w_i with average world prices of top 5 crops as an IV.



(a) OLS (b) First Stage (c) Reduced Form

Calibration of destruction spillovers

2SLS estimation to recover the semi-elasticity of productivity to violence

$$\log A_n = -\varepsilon \times \texttt{violence}_n + \text{residual}_n \tag{28}$$

Reverse causation from income on violence (rapacity effect) $\rightarrow$ instrument with a model-driven supply shifter of violence $\sum_i \left(\frac{\xi_{in}}{\psi_i}\right)^{-\frac{\gamma}{1-\gamma}}$ controlling for a shifter of trade potential $\sum_i \left(\frac{\tau_{in}}{A_i}\right)^{1-\sigma}$

- $\texttt{violence}_n$ comes directly from the data
- $\log A_n$: predicted productivity recovered from model inversion

  $\rightarrow \varepsilon = -0.0075$ (s.e. 0.002, first stage F stat: 15.2)

  $\rightarrow$ one additional ACLED event decreases productivity by 0.75%

- Robustness: Use observed night light. Pros: from data / Cons: indirect proxy of A_n
- Both approaches yield statistically significant estimates in the same quantitative ballpark

Calibration of destruction spillovers: Reduced form evidence

Figure: Productivity

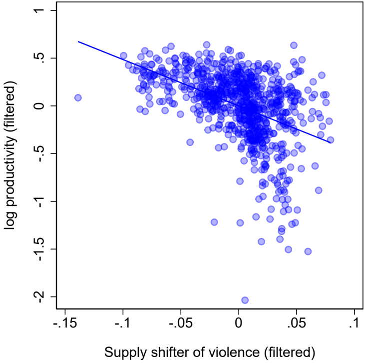


Figure: Night Light