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

Remi Jedwab (GWU), Federico Haslop (GWU),
Roman Zarate (World Bank) & Carlos Rodríguez-Castelán (World Bank)*

Abstract

Due to identification concerns, empirical studies of the economic effects of climate change typically rely on "climate shocks" for their analysis, hence year-to-year climate variations. The economic effects of *slow* and *permanent* changes in climate-driven geographical conditions, i.e. climate change as defined by the IPCC, have been investigated very little in comparison. We focus on Lake Chad, a vast African lake the size of Israel or Massachusetts that, for exogenous reasons, shrunk by 90% between the 1960s and the late 1980s. While water supply decreased, land supply increased, generating a priori ambiguous effects, and making the increasing worldwide disappearance of lakes an important trend to study. For Cameroon, Chad, Nigeria and Niger – 25% of sub-Saharan Africa's population –, we construct a novel data set tracking population patterns at a fine spatial level from the 1940s to the 2010s. Difference-in-differences show slower growth in the proximity of the lake, but only after the lake started shrinking. Thus, the negative water supply effects on fishing, in addition to farming and herding, outweighed any positive land supply effects. A quantitative spatial model is used to rationalize these results as well as estimate aggregate welfare losses. The model also allows us to study the aggregate and spatial effects of policies related to migration, trade, land use, roads, and cities.

JEL Codes: Q54; Q56; Q15; Q20; R11; R12; O13; O44

Keywords: Climate Change; Aridification; Shrinkage of Lakes; Natural Disasters; Environment; Water Supply; Land Supply; Rural Decline; Agricultural Sectors; Adaptation; Land Use; Africa

---

*Corresponding author: Remi Jedwab: Department of Economics, George Washington University. Federico Haslop: PhD candidate, Department of Economics, George Washington University. Roman Zarate, Development Research Group, The World Bank. Carlos Rodríguez-Castelán, The World Bank. We thank Clare Balboni, Bruno Conte, Klaus Desmet, Jonathan Dingel, Vernon Henderson, Matth Kahn, Guy Michaels, David Krisztian Nagy, Nathan Nunn, Giovanni Peri, Jacopo Ponticelli, Esteban Rossi-Hansberg and David Yanagizawa-Drott and seminar audiences at Copenhagen Business School (UEA), George Mason, Georgetown (WADES), George Washington, UCSD (PACDEV), and the World Bank for helpful comments. We gratefully acknowledge research support provided by Andrew Durrer, Madeline De Quillacq and Xuerui Yang. The findings, interpretations, and conclusions expressed in this paper are entirely ours. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors or the governments they represent.

According to the IPCC, "climate change refers to a 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 or longer."[1] In addition, "warming of the climate system is unequivocal, and since the late 1950s, many of the observed changes are unprecedented over decades to millennia" (IPCC, 2013).

Empirical studies of the causal effects of climate change typically rely on "climate shocks" for their analysis, i.e. year-to-year variations in temperature and rainfall. While such studies have improved our understanding of the reduced-form effects of climate changes, they do not examine "changes in the mean" over several "decades or longer," which is how climate change is defined according to the IPCC. The negative effects of climate variations should compound over time the longer they last. Since climate change is unfolding gradually, agents also engage in a wider set of adaptations. Thus, it is difficult to infer from climate shocks what the effects of climate change could be.

More theoretical studies simulate the effects of future climate change, i.e. changes in means over several decades or centuries. While such studies have deepened our understanding of the mechanisms by which climate change may have aggregate and spatial effects in the future, they are predictive exercises. As such, they do not aim to study the effects of the climate change that has been occurring since the 1950s.

To investigate the "real" effects of climate change, one needs: (i) A permanent change in climate-driven geographical conditions; (ii) The change must take place over several decades; (iii) The change must be exogenous, thus allowing the researcher to study its local and aggregate effects; (iv) Localized economic data must be available during the change as well as before the change. This is particularly difficult for the poorest countries that will be most affected by future climate change, as in sub-Saharan Africa; (v) A model that helps us rationalize the economic and spatial effects; and (vi) The model must be able to generate clear policy prescriptions.

In this paper, we combine reduced-form evidence and theory to study over a 70 year period the local and aggregate economic effects of the almost complete disappearance of Lake Chad, historically the 11th largest lake in the world. Lake Chad lost 90% of its surface water area – 23,000 sq km – between the mid-1960s and the late 1980s (see Figures 1-2). This is equivalent to the total area of Israel plus the West Bank and Gaza, El Salvador, or Massachusetts. While its water level has been slightly recovering since the 1990s, it is still on average 80% less than in the mid-1960s. However, as water supply decreased and land supply increased, it generated a priori ambiguous economic effects.

We focus our analysis on four countries that were low-income countries for most

[1] See https://www.ipcc.ch/sr15/chapter/glossary/, last accessed 11-15-2021.

of the 20th century and whose territory borders Lake Chad: Cameroon, Chad, Niger and Nigeria (see Figure 3). These countries account for 25% of the population of sub-Saharan Africa today, making Lake Chad's shrinkage one of the most important events to have economically affected the continent. Next, the shrinkage of the lake starting in 1965 had to do with reduced rainfall in a fifth country more than 800 km away from the lake itself, the Central African Republic (CAR). This is because the Chari and Logone rivers flow from the CAR through Chad and into Lake Chad, which is a sink. Once one controls for proximity to these rivers, the lake's drying is plausibly "exogenous."

To conduct our analysis, we first use census and administrative count data to construct a novel data set tracking population patterns at a fine spatial level over 70 years: 113, 138, 119 and 83 subdistricts in Cameroon, Chad, Niger and Nigeria, respectively. For each country, we then use (relative) population growth as our main outcome of interest, finding in a panel difference-in-difference (DiD) framework: (i) no differential effect of proximity to the lake before 1965; (ii) a very negative effect of proximity to the lake in 1965-1990; and (iii) an effect that remains strongly negative post-1990. In the long-run, locations close to the lake have been growing 46% slower than other locations in Chad, and 27-31% slower in the other three countries.

90 percent of rainfall comes from the evaporation of oceans, seas and lakes (USGS, 2021a). In warmer climates, lakes also have a cooling effect on their direct environment.[2] Therefore, when a large lake dries out, it permanently alters climate conditions. Lake Chad is an endorheic lake, meaning that it loses 100% of its water through evaporation. The DiD indeed suggests that rainfall decreased and temperature increased close to the lake. Thus, (global) climate change begets (local) climate change.

Our interpretation of the results is that the fishing, farming, and herding sectors were negatively impacted by the lake receding. As real incomes and welfare more generally decreased in the area, households likely migrated away to other areas away from the lake. Therefore, the negative effects of the loss in water supply, a direct or indirect input in the three sectors, must have outweighed the positive effects of increased land supply.

To rationalize the effects, we develop a quantitative spatial model with multiple locations and four economic sectors: fishing, farming, herding, and an urban sector. We use data c. 1965 in Cameroon, Chad, Niger and Nigeria to calibrate the set of parameters and solve the model before and after the shrinkage of the lake, taking into account various mechanisms by which it may have affected the four sectors as well as amenities. Overall, depending on the country, the model is able to explain between half and two-

[2]USGS (2021b) writes: "The oceans and lakes help regulate the temperature ranges that billions of people experience in their towns [...]. Water [...] takes longer to heat up and longer to cool down than do land masses, so cities near the oceans will tend to have less change and less extreme temperatures."

thirds of the shock, and aggregate welfare losses amount in the long-run to 8% in Chad and 3-4% in the other countries. The model allows us to improve our understanding of the economic effects of lake disappearances, for example discuss why the fishing productivity shock was strong, and the land supply effect not so strong, in our context.

Finally, armed with the model we can study the aggregate and spatial effects of policies related to migration, trade, land use, roads, and cities. In particular, policies that facilitate migration, trade, rural land development in the former lake areas, road construction, and the absorption capacity of locations all reduce the aggregate welfare loss caused by the shrinkage of the lake. Policies aimed at restoring Lake Chad to its former glory, for example via mega-engineering projects that would divert water from the Congo River basin to Lake Chad, are not economically sustainable.[3]

In terms of contributions, our paper is related to a nascent body of literature that use spatial-economic models to estimate the aggregate and spatial effects of climate change (Desmet and Rossi-Hansberg, 2015; Costinot, Donaldson and Smith, 2016; Conte, Desmet, Nagy and Rossi-Hansberg, 2020; Desmet, Kopp, Kulp, Nagy, Oppenheimer, Rossi-Hansberg and Strauss, 2021; Conte, 2021).[4] The studies focus on the effects of future higher temperatures or increased coastal flooding. In contrast, we study the effects of climate change since the 1960s. First of all, it is important to study the effects of past climate change as it can help researchers improve their predictive analysis of future climate change impacts. For example, in addition to farming we consider fishing and herding. We also study how climate change may cause lakes to disappear. These are sectors and shocks that have not been included in the previous analyses. Second, focusing on past climate change can help us assess the validity of spatio-economic models used to estimate the effects of future climate change. It appears that our quantitative spatial model (QSM) performs well in our *historical* context, which should give more credence to QSM-based analyses of *future* climate change. Finally, while most of the above-mentioned studies consider the world, we focus on four West African countries among the most likely to be impacted by climate change in the future.[5] Unfortunately, these countries are also characterized by a dearth of historical localized data. Nonetheless, we show that with our data compiling effort and methodology it is still possible to study the effects of climate change in data-poor countries.

[3]One such project called Transaqua has been advocated by the Lake Chad Basin Commission (LCBC), an intergovernmental organization overseeing water usage in the basin. With the support of various governments, the LCBC has lobbied the United Nations and other international organizations in order to fund the project whose estimated cost is US$50 billion (Sayan et al., 2020; The Conversation, 2021).

[4]Auffhammer (2018) emphasizes the importance of models in studying the economic effects of climate change. Of course, there are models without any specific spatial component (e.g., Burke et al., 2015).

[5]Chad and Niger are two Sahelian countries among the poorest in the world. As such, they are likely to be very negatively impacted by climate change and continued aridification in the future.

Other studies of the effects of the climate have been more reduced-form in nature. Most of these studies have typically relied on year-to-year climate deviations to identify causal effects and have studied the following outcomes (see Dell et al. (2014) for a survey): agricultural development (Schlenker et al., 2006; Deschenes and Greenstone, 2007; Felkner et al., 2009; Burgess and Donaldson, 2010; Hsiang and Meng, 2015; Burke and Emerick, 2016; Mahajan and Yang, 2020; Rosenzweig and Udry, 2020; Aragon et al., 2021; Miller et al., 2021), land prices (Mendelsohn et al., 1994; Schlenker et al., 2005), mortality (Deschenes and Moretti, 2009; Deschenes and Greenstone, 2011; Turner et al., 2012; Barreca et al., 2015; Carleton et al., 2020; Heutel et al., 2021), and migration / structural change (Deschenes and Moretti, 2009; Bohra-Mishra et al., 2014; Cattaneo and Peri, 2016; Baez et al., 2017; Jessoe et al., 2018; Kleemans and Magruder, 2018; Colmer, 2021; Liu et al., 2021).[6] These studies have contributed to our understanding of the mechanisms by which the climate impacts economic development. However, most studies do not focus on climate change *per se*. Also, given the reduced-form focus, some of these studies only capture local effect instead of aggregate welfare losses.

More generally, with our focus on a natural experiment that "mimics" climate change and our QSM analysis, we combine the advantages of the empirical and theoretical (predictive) strands of the climate change and economic development literature.

Additionally, to our knowledge this is the first paper studying the short and long-term (causal) effects of a shrinking lake on economic development. As such, unlike existing studies on coastal flooding (Kocornik-Mina et al., 2020; Keys and Mulder, 2020; Desmet et al., 2021; Michaels et al., 2021; Balboni, 2021; He et al., 2022), we study the effects of water disappearing, not submerging land and roads. Floodings lead to crop losses and destructions in cities. Lake recessions have more ambiguous effects in theory, because potentially valuable land becomes available. But the emergence of new land raises questions regarding property rights and other aspects of rural land development.[7]

Lake disappearances are important to study in and of themselves. Lakes are major economic assets for many regions of the world, for example the Caspian Sea in Eastern Europe, Central Asia, and Western Asia, or Lakes Victoria, Tanganyika, Malawi, Bangweulu and Turkana in East Africa. Africa has ten of the fifty largest lakes in the world and "Africa's lakes contribute significantly to the continent's socio-economic

[6]There are studies on the climate and human capital (Deschênes et al., 2009; Maccini and Yang, 2009; Shah and Steinberg, 2017; Rosenzweig and Udry, 2020; Corno et al., 2020), cities (Barrios et al., 2006; Henderson et al., 2017; Peri and Sasahara, 2019), conflict (Miguel et al., 2004; Miguel and Satyanath, 2011; Couttenier and Soubeyran, 2014; Harari and Ferrara, 2018) and economic production (Dell et al., 2009; Jones and Olken, 2010; Barrios et al., 2010; Dell et al., 2012; LoPalo, 2020; Somanathan et al., 2021).

[7]There is a related literature on the importance of water for agricultural production. Most studies focus on groundwater irrigation (e.g., Sekhri, 2011, 2014; Hornbeck and Keskin, 2014; Blakeslee et al., 2020).

development" (UNEP, 2006).[8] Other major examples of drying lakes include the Aral Sea (Kazakhstan and Uzbekistan), formerly the fourth largest lake in the world, and Lake Urmia (Iran), formerly the largest lake of the Middle East.[9] In the United States, the Great Salt Lake has lost two thirds of its area since the 1980s, as a result of which "Utah faces an 'environmental nuclear bomb" (New York Times, 2022).[10] Likewise, the dry lake bed of the now disappeared Salton Sea in Southern California has become "the biggest manmade source of hazardous dust in the United States" (The Atlantic, 2015).[11]

Climate change is a multi-faceted phenomenon (Hsiang and Kopp, 2018) and many lakes and rivers are drying in the world and will continue to do so with climate change (UNEP (2006); Web Appx. Section A provides more examples of dying lakes and rivers). Economic analyses of the costs, but also benefits, of these trends are thus needed.

Lastly, our paper is related to literature on the economic effects of natural disasters. Kahn (2005), Strobl (2011), Boustan et al. (2012), Cavallo et al. (2013), Hornbeck and Naidu (2014), Guiteras et al. (2015), Gröger and Zylberberg (2016), Chen et al. (2017b) and Kocornik-Mina et al. (2020) study the effects of floods, tornadoes, hurricanes or typhoons, whereas Hornbeck (2012) study the effects of the Dust Bowl in the United States. Our study and these studies have in common to show that migration is one of the margins of adjustment through which countries adapt to natural disaster shocks. However, unlike our shock that took place over at least two decades, the shocks considered in these studies lasted only one year or no more than a few years. Furthermore, the previous studies are reduced-form in nature. As such, they do not quantify the aggregate welfare losses associated with these events, nor do they use a QSM to quantify how migration (and other policies) may reduce such losses.

The paper is structured as follows: Section 1. provides the background. Section 2. introduces our novel data. Sections 3., 4. and **??** present reduced-form results on total population, cities and the climate, respectively. Section 5. presents the quantitative spatial model analysis and discuss the mechanisms and policies. Section 6. concludes.

[8]Other large lakes are usually found in North America, Russia or Central Asia.

[9]Both shrunk to less than 20% of their former size. However, the Aral Sea dried up because its feeding rivers were diverted by Soviet irrigation projects and Lake Urmia dried up because its feeding rivers were dammed. In contrast, Lake Chad dried up for mostly natural — and locally exogenous — reasons.

[10]The New York Times (2022) writes: "Climate change and rapid population growth are shrinking the lake, creating a bowl of toxic dust that could poison the air around Salt Lake City. [...] The lake bed contains high levels of arsenic and as more of it becomes exposed, wind storms carry that arsenic into the lungs of nearby residents, who make up three-quarters of Utah's population."

[11]The Atlantic (2015) writes: "Los Angeles has spent more than $1.2 billion dollars trying to suppress the dust, pouring 30 billion gallons of water onto the lake bed each year, but air-quality problems remain."

1. Background: Why Lake Chad Shrunk

Lake Chad is a sink that receives water from the Chari-Logone river system (see Figure 4). The river system primarily originates from heavy rainfall in the mountainous areas of the Central African Republic (CAR) more than 800 km away from the lake itself. Rainfall in Eastern Cameroon and rainfall in the Southeastern areas of Chad also marginally contribute to the system (Magrin et al., 2015; Pham-Duc et al., 2020). However, because the discharge rate of the Chari and Logone rivers depends almost exclusively on rainfall in Northern CAR, lack of rainfall over the CAR after 1963 – due to global climate change disproportionately impacting Central Africa starting in the early 1960s – was by far the main reason behind the large drop in water area also observed after 1965 (see Figure 2) (Evans and Mohieldeen, 2002; Magrin et al., 2015; Pham-Duc et al., 2020). See Web Appx. Section C for more details on the exact timing of these patterns.[12]

The fact that the lake's water level is primarily determined by rainfall in another country south of our region of study provides reassurance that the results will not be explained by reverse causality. However, this does not rule out other sources of bias.

Because the rivers go through the territory of Cameroon and Chad (Fig. 4), outcomes in the lake's surroundings may not be independent of outcomes upriver. Indeed, drier rivers due to less rain in CAR may have also affected other locations along the river system. Control areas farther away from the lake are then also affected. Yet, this should only lead us to under-estimate how negative the effects of the lake's shrinkage are.

Furthermore, historical data on discharge rates for various sites along the river system from the 1940s to the 1980s suggest that the decline in the discharge rate of the rivers occurred c. 1963, at the same time as rainfall started declining in the CAR, and two years before the lake started shrinking. As seen in Figure 4 which shows the sites and the decline in their mean annual discharge rate between before and after 1964, most of the collapse at the closest place to the lake, N'Djamena (-471 m^3/s), came from Bousso (-354), hence the Chari River. The contribution of the rivers from Cameroon – via the Logone River and Bongor (-62) – was marginal. In turn, almost all the decline in the Chari came from the CAR, not Chad. Am Timam in Chad shows a decrease of -5 vs. -143 for Sarh and -252 for Moissala, the two entry points of the CAR's rainfall into the Chari.[13]

Also, irrigation withdrawals were limited, as most irrigation systems were basic.

[12]Web Appx. Fig. C.1 shows stable rainfall patterns before 1963 and far stronger rainfall declines after 1963 in the mountainous areas of the Central African Republic than in the close subdistricts to Lake Chad in the four countries of study (Cameroon, Chad, Niger, Nigeria). For these areas, the decline in rainfall can be observed from 1970, hence several years after the lake started shrinking. Indeed, we show later that the post-1965 decrease in rainfall close to Lake Chad was due to the drying of the lake itself.

[13]The full patterns for each site are discussed in Web Appx. Section C and shown in Web Appx. Fig.C.3.

Recent studies document that irrigation withdrawals and other anthropogenic activities cannot explain the lake's shrinkage (Pham-Duc et al., 2020; Nour et al., 2021).

To conclude, the decline of rainfall in another country was by far the main driver of the lake's shrinkage, a conclusion also supported by experts of the lake. Nonetheless, we will control for proximity to the Chari-Logone river system throughout the analysis.[14]

The river system is also not present in Niger or Nigeria, making these two countries potentially cleaner environments for our analysis. However, some minor rivers of the Chari-Logone system follow the Cameroon-Nigeria border (Web Appx. Fig. C.2). As such, we will also control for proximity to the extended Chari-Logone river system in Nigeria. This makes Niger the cleaner environment between Niger and Nigeria.

In addition, despite possibly different levels of exogeneity across countries, we will find relatively similar local growth patterns for the four countries. This gives us confidence that we are effectively controlling for any potential bias generated by the river system. This also reassures us about the external validity of our results.

Another characteristic of Lake Chad that must be considered is the heterogeneous degrees of dryness that were experienced over its different regions. Splitting Lake Chad in half lies what is called the *Grande Barrière*, an elevated area that in dry years divides the lake in a southern pool and a northern pool. It is only when the water level of the southern pool is high enough that water crosses the Grande Barrière to replenish the northern pool (Evans and Mohieldeen, 2002; Magrin et al., 2015; Pham-Duc et al., 2020). During the Large Lake Chad era (pre-1965), this geological feature remained submerged, rendering it irrelevant. However, as the Chari-Logone Rivers' discharge rate declined, the Grande Barrière created a northern sink that dried almost completely in the 1980s, and a southern sink that, although smaller in size, retained an area of open water (Figure 5) (Magrin et al., 2015). Note that we will also exploit this fact in our analysis.

Finally, Boko Haram, a terrorist group, started its insurgency in the North-East of Nigeria in July 2009 (Blankespoor et al., 2020). To avoid conflating the effects of the lake and the effects of Boko Haram, we prioritize population estimates before July 2009 in our analysis. For example, Chad's 2009 census took place in May-June. Boko Haram then did not establish itself in Niger before 2014. Niger's 2012 census is thus reliable.

[14]Since Chad's Southern areas are closer to the CAR's mountainous areas, it is safer to also control for the subdistrict's latitude interacted with year fixed effects, which we do for the four countries. Controlling for the effects of proximity to the river system over time in Chad also controls for proximity to the CAR.

2. Main Population Data for the Reduced-Form Analysis

We use subdistrict-level population data for the four countries. An analysis of the impact of the lake's drying demands localized data for the period 1965-1990 (shrinking Lake Chad phase) and the pre-1965 period (large Lake Chad phase). Due to this, total population figures are the best, and only, measures available.

To further illustrate this point, the Demographic and Health Surveys and existing household/labor force surveys are not available before the mid-1990s. Likewise, only the 1976, 1987 and 2005 population censuses of Cameroon are available on IPUMS. Since the lake's level was already low by 1976, it renders the following years useless for this analysis as well. Nighttime lights are also only available from the year 1992. Finally, the various censuses that took place over time in each country are not consistent with each other, which constrains our ability to track other outcomes over such a long period.

Few population censuses took place in the four countries and even when population data is available, it is not at a fine spatial level like United States county data. Typically, the sources that we were able to get ahold of report population data at the "subdistrict" level. However, subdistrict boundaries changed over time. As such, we aggregated subdistricts to reconstruct a set of consistently defined subdistricts over periods spanning 60-70 years. Our data set contains 119 subdistricts for Niger (1951-2012), 113 for Cameroon (1963-2005), 138 for Chad (1948-2009), and 93 for Nigeria (1952-2006) (see Figure 3). These correspond to third-level administrative units: *communes* in Niger, *arrondissements* in Cameroon, *sous-prefectures* in Chad, and *divisions* in Nigeria.

In Niger (119 subdistricts), we have total population data in 1951, 1956, 1959, 1962, 1969, 1988, 2001, 2012, 2013 and 2017. Data for the years 1951, 1956, 1959, 1962, 1969, 2013 and 2017 come from administrative sources (often administrative censuses). Values for the years 1988, 2001 and 2012 come from population censuses.[15]

The Cameroon data set (113 subdistricts) includes the years 1963, 1967, 1976, 1987 and 2005. Information for 1963 and 1967 comes from administrative sources. Population figures for the years 1976, 1987 and 2005 are based on population census counts. No census has taken place since 2005.[16] We only have subdistrict population data for one year (1963) before the lake started shrinking. To examine whether the parallel trends assumption holds for Cameroon, we will use total population data at the district level. More precisely, we reaggregate the 113 subdistricts into 47 districts, which allows us to add one year of pre-1965 data (1956; source = administrative census).

[15]Administrative censuses are population counts relying on official registers and other national files.
[16]For example, the 2018 population census was postponed indefinitely.

The Chad data set (138 subdistricts) includes the years 1948, 1953, 1965, 1993 and 2009. Population measures for the years 1948, 1953 and 1965 are based on administrative sources. For the year "1965", we use information from the 1962 administrative census and 1964 demographic survey as our baseline. When needed, we adjust the population levels that we obtain using information from the 1968 administrative census. We call this year "1965" because 1965 is the mid-year between 1962 and 1968. Lastly, we use census population figures for the years 1993 and 2009.[17]

Finally, the Nigeria data set (83 subdistricts) includes the years 1952, 1963, 1991 and 2006. However, the reliability of the 1963 census has been questioned by experts (Ahonsi, 1988). We also do not use the 1973 census whose results were never published due to accusations of political manipulation (Ibid). As such, measurement error in the dependent variable is possible. If classical, it only affects the precision of our estimates.

Mean subdistrict area is 10, 4, 9 and 11 thousand sq km in Niger, Cameroon, Chad, and Nigeria, respectively. In comparison, the mean U.S. county is about 3 sq km. Were the subdistricts shaped like circles, their radius would be about 36-59 km.

3. Main Reduced-Form Effects on Total Population

The historical drop in water levels starting c. 1965 and the relative recovery of the lake after 1990 allow us to examine how the shrinking of a lake affects nearby communities. To do so, we exploit a simple panel difference-in-difference (DiD) framework and study the effect of proximity to the lake on total population patterns. For subdistricts s and years t and *each country at a time*, we first estimate the following model:

$$ln(Tot.Pop.)_{s,t} = \alpha + \sum_v \beta_v Prox.Lake_s \times \mathbb{1}(v = t) + \lambda_s + \theta_t + X_s B_{s,t} + District_s * t + \mu_{d,t} \quad (1)$$

where $ln(Tot.Pop.)_{s,t}$ is the log of total population in subdistrict s in year t and the variables of interest are the interactions between the time-invariant measure of proximity to the lake – the log of the Euclidean distance from each subdistrict's centroid to the lake – and year dummies (we omit the latest year available before the year 1965).

We add subdistrict (λ_s) and year (θ_t) fixed effects, as well as district-specific linear trends ($D_s \times t$) to control for local patterns of economic development at the district level over time. We then use Conley standard errors (distance cut-off of 100 km).[18]

Furthermore, our specification includes several time-invariant controls ($X_s B_{s,t}$) that we interact with year effects. We first add the logged Euclidean distances to the largest

[17] 1968 is three years after the lake started shrinking (1965). If this was econometrically consequential, that should only lead us to under-estimate how negative the effects of the lake shrinking was.

[18] We consider 31, 47, 36, and 24 districts in Niger, Cameroon, Chad and Nigeria, respectively. The district boundaries more or less correspond to *departements*, *prefectures* or *states* in the 1960s.

city and the capital city, and their square.[19] This controls for spatial development patterns related to economic or political centralization (or decentralization).[20]

For historical reasons, northern areas are less developed, and have been growing slower, than southern areas in the four countries (e.g., Boone and Simson, 2019; The World Bank, 2020). Geographical differences also correlate with latitude, with declining vegetation density as one moves north and, in the case of Chad and Niger, desertification (Mortimore, 1989). To control for this North-South gradient, we include the latitude of the subdistrict's centroid interacted with year fixed effects.

We add two dummies for whether the subdistrict is crossed by a major river (Fig. 4) or a minor river (Web Appx. Fig. C.2) of the Logone-Chari river system, interacted with year dummies. This controls for the potential local effects of changes in discharge rates.

Finally, Nigeria became between the 1960s and the 1970s Africa's largest oil producer, which increased spatial inequality and raised questions about oil-revenue sharing across states (Ahmad and Singh, 2003; Zainab, 2022). We add various time-invariant controls interacted with year dummies: (i) a dummy if there were oil deposits in the subdistrict c. 1960;[21] (ii) the logged Euclidean distances to Port Harcourt and Benin City, the informal capital cities of the oil-producing Delta region, and their squares; and (iii) the logged Euclidean distance to Kano, the North's capital, and its square. A large share of oil revenues is indeed shared with the Delta and Northern regions.[22]

Niger. Niger possibly offers the best environment for our analysis. Its territory does not contain any river of the Chari-Logone system and we have more years of data (119 subdistricts x 17 years = 2,023 obs.). Figure 6(a) shows the effects (β_v) of proximity to the lake in each year (1962 is the omitted year). Here, *proximity to the lake* is the negative of the logged Euclidean distance between each subdistrict's centroid and the centroid of the lake area that is within Niger's territory (centroid "(1) Niger Only" in Fig. 5).

The patterns in 1951-1962 suggest parallel trends. In 1969, we see a large negative effect of -0.23**. (exp(-0.23)-1)*100 = -21%. By then, the full Lake Chad had shrunk by 22%. This effects is more negative in 1988, at -0.41***, or -34%. The lake's water level had then collapsed by 91%. Thus, halving the distance from the lake is associated with a 34% relative decline in population. Alternatively, a one standard deviation in proximity to the lake is associated with a 0.48 standard deviation decrease in log population. The

[19] The largest city is not the capital city in Cameroon (Douala vs. Yaoundé) and Nigeria (Lagos vs. Abuja).

[20] For Chad, recall that subdistrict population data c. 1965 uses data from the years 1962-1964 as a baseline. For about half of the country, information from 1968 is also used. We thus include as a control a dummy if 1968 information was used, which we interact with year fixed effects.

[21] The source is *Petrodata* from Prio. Accessed 06-17-2022. Url: https://www.prio.org/data/11.

[22] Kano, Benin City and Port Harcourt are the second, fourth and fifth largest city today, respectively.

effects remain negative after 1990. It is -0.31** (-27%) in 2001 and -0.33* (-28%) in 2012.

Table 1 shows the results in table form except that we only report the effects c. 1990 (for the year 1988) and c. 2010 (2001 and 2012), again relative to the year 1962. Results hold if we: (i) Use the centroid of the full Lake Chad (centroid (2) in Fig. 5) instead of the centroid within Niger (col. (2)); (ii) Include a dummy if the subdistrict contains the Komadugu-Yobe River, which we interact with year dummies (col. (3)). It is a small river that follows the Niger-Nigeria border and flows into the lake. Its mean annual discharge rate was stable around 15-20 m^3/s for most of the period, and no discontinuity can be observed c. 1965 (Martinsson, 2010, Fig. 1.3). In comparison, the discharge rate for the Logone-Chari in N'Djamena close to the lake was 1,400 m^3/s on average pre-1965, about 80 times more; (iii) We control for log mean annual rainfall and log mean temperature in $[t\text{-}2;\, t]$ and their square (col. (4)), in case some of the shrinkage was driven by local climatic conditions;[23] and (iv) Use 250 km instead of 100 km for the Conley SEs.

Our baseline specification compares population growth patterns for locations closer vs. locations farther away from the lake, conditional on the fixed effects, district trends, and the controls. It has the advantage of making us estimate only one coefficient per year. However, it does not tell us how the effect varies with proximity to the lake. We use model (1) but instead of having only one variable capturing proximity to the lake we now employ three dummies based on the Euclidean distance between a subdistrict's centroid and the selected lake centroid (in this case, the centroid within Niger's territory). More specifically, we consider 0-150, 150-300 and 300-450 km:[24]

$$\begin{aligned} ln(Tot.Pop.)_{s,t} = \alpha + \sum_{v} \beta_{150,v} Lake_{150} \times \mathbb{1}(v=t) + \sum_{v} \beta_{300,v} Lake_{300} \times \mathbb{1}(v=t) \\ + \sum_{v} \beta_{450,v} Lake_{450} \times \mathbb{1}(v=t) + \lambda_s + \theta_t + X_s B_{s,t} + District_s * t + \mu_{d,t} \end{aligned} \quad (2)$$

Col. (1) of Table 2 reports the interacted effects for the closest year to 1990 (1988) and 2010 (2001). We find strong negative effects within 150 km (c. 2010, (1-exp(-0.49))*100) = -39%). The effects for the 150-300 km bin are as strong as the effect within 150 km. No effect is found 300-450 km away. Thus, the effect decreases with distance from the lake.

Cameroon. For Cameroon (113 subdistricts x 5 years = 565 obs.), we find similar effects for eq. (1) (see Fig. 6(b)). Note that we use the centroid of the Lake Chad area that is within Cameroon's territory (centroid (3) in Fig. 5). The c. 1990 effect is -0.40***, or 33%.

Since we only have one pre-1965 year (1963), we cannot test for parallel trends.

[23] See Web Appx. Section B for details on the rainfall and temperature data.

[24] Were the subdistricts shaped like circles, their radius would be about 36-59 km. We cannot consider bins that are too small (e.g., 50 km). Likewise, if the bins are too large (250 km), we may miss local effects.

Relying on districts instead, we add the year 1956 to the analysis (47 districts x 6 years = 282 obs.). We then use the same specification as for the subdistrict analysis. Web Appx. Fig. C.4 shows that people were, if anything, moving closer to the lake before 1965. Thus, if there is a pre-trend, it implies that our estimates are conservative estimates.

Web Appx. Table C.1 shows that the subdistrict results hold if we use the centroid of the full Lake Chad, include the climate controls, or use 250 km for the Conley SEs.

Col. (2) of Table 2 then reports the bin-specific effects for the closest year to 1990 (1987) and 2010 (2005). We find strong negative effects in the short and long run, and the effects are particularly strong within 150 km (c. 2010, (1-exp(-1.41))*100) = -76%).

Nigeria. We find similar effects for Nigeria (83 subdist. x 4 years = 332 obs.; see Fig. 6(d)). Note that we use the centroid of the lake area within Nigeria's territory (centroid (7) in Fig. 5). No pre-trend is observed. The c. 2010 (2006) effect is -0.37*, or -31%.

Web Appx. Table C.2 shows that results hold if we use the centroid of the full Lake Chad, control for the presence of the small Komadugu-Yobe (inflow) river as we did for Niger, include the climate controls, or use 250 km for the Conley SEs.

Col. (4) of Table 2 then reports the bin-specific effects for the closest year to 1990 (1991) and 2010 (2006). We find strong negative effects in the short and long run, and the effects are particularly strong within 150 km (c. 2010, (1-exp(-1.16))*100) = 69%).

Chad. For Chad, we have 138 subdistricts x 5 years = 690 obs. Chad contains in its territory portions of both the northern and southern pools of the lake. Due to the Grande Barrière, the northern pool dried out. In contrast, some areas of the southern pool were never completely dry, hence the need to study the effects for both pools.

Considering the centroid of the portion of the northern pool that is contained within Chad's territory (centroid "(4) North Pool only" in Fig. 5), we find similar effects as before (see Fig. 6(c)). No pre-trend is observed. The c. 2010 effect is then -0.62***, or -46%.

Web Appx. Table C.3 shows less negative effects if the lake centroid is defined using the whole portion of the lake within Chad (centroid (5) in Fig. 5), or the portion corresponding to the southern pool only (centroid (6) in Fig. 5). If we simultaneously include (-) log Euclidean distances to the northern and southern lake centroids, we only find negative significant effects for the distance to the northern centroid.

Next, we utilize Lake Fitri as a placebo check of our analysis of the effects of Lake Chad shrinking. Lake Fitri's location can be seen in Figure 3. While Lake Fitri's water levels have changed over time, it has not shrunk like Lake Chad.[25] Because Lake Fitri

[25]Lake Fitri is located in a seasonally inundated plain that is fed by the Batha River which carries water all the way from the Ouaddai massif in the East (Hughes et al., 1992). The size of Lake Fitri thus depends

provides households with similar livelihood possibilities as Lake Chad does, it provides a good placebo test of whether the effects observed in Lake Chad are a consequence of changes in lake-related economic activities instead of economic effects due to Lake Chad only. However, no negative effect is found for Lake Fitri (see Web Appx. Table C.3).

We can add a dummy for whether the subdistrict contains the Bahr el-Ghazal – a dry riverbed that was pre-1900 an outflow river of the lake (Collelo, 1988) – interacted with year dummies, include the climate controls, or use 250 km for the SEs (same table).

Finally, col. (3) of Table 2 reports the bin-specific effects for the closest year to 1990 (1993) and 2010 (2009). We find strong negative effects in the short and long run, and the effects are particularly strong within 150 km (c. 2010, (1-exp(-1.03))*100) = -64%).

Overall. We find similar spatial patterns in the four countries, which should assuage concerns related to causality and measurement error. Circa 2010, the population-proximity elasticity is -0.62 for Chad vs. -0.37 for Nigeria, -0.36 for Cameroon and -0.31 for Niger. We will use our quantitative spatial model (QSM) analysis below to investigate why the reduced-form effect is higher for Chad than for the three other countries.

Figure 6(e) shows the percentage water loss and the estimated (relative) population losses for the four countries (expressed in percents as well). The average population loss c. 1990 and c. 2010 was 37% and 31%, respectively (for the elasticity: -0.46 and -0.38).

4. Other Reduced-Form Effects

Rural population. We showed how the lake's shrinking negatively impacted total population levels in the areas close to the lake. Since rural sectors – fishing, farming and herding – were reliant on the lake's existence and since the regions surrounding the lake were little urbanized in 1965, our interpretation is that this population loss was driven by rural decline, as opposed to urban decline.[26]

To test this more formally, we employ the same panel-DiD model at the subdistrict level we used for log total population but consider log rural population instead. To construct rural population (total population minus urban population), we obtain the total population of cities for each country-year with available total population data.

Following Bairoch (1988), we define a city as any locality with at least 5,000 inhabitants at any point during the period of study.[27] We thus focus our data compiling efforts on localities that reached the threshold of 5,000 inhabitants at any point. As explained in Web Data Appx. Section D, we rely on population censuses

on rainfall at the border between Chad and Sudan, not the Central Africa Republic in the South.

[26]The urban share of Cameroon, Chad, Niger and Nigeria was 17%, 8%, 7%, and 17% in 1965, respectively (UN, 2018). Since lake regions were typically poorer, they were also even less urbanized.

[27]The mean population threshold used in the world to define cities is 4,500 (Jedwab and Vollrath, 2015).

and administrative counts to obtain a population estimate for as many cities-years as possible. Ultimately, our selection process yields 186, 100, and 166 cities in Cameroon, Chad, and Niger, respectively. For each city, we know its population when it is above 5,000. When it is below 5,000, we replace it with 0 (since there are many cities for which we do not know the population when it is below 5,000). For Nigeria, consistent data on localities with 5K+ inhabitants over time does not exist, leading us to omit Nigeria.

For each subdistrict-year, we then obtain the total population of these cities with 5K+ inhabitants. However, we also consider the 20K population mark, thus replacing any population estimate below this threshold with 0. Rural population estimates are based on these thresholds. We also consider 20K because smaller cities in the 5K-20K range may include a significant share of primary sector workers. For example, fisher people sometimes live in coastal towns. As such, while the primary sector and rural locations overlap, they do not do so completely (Gollin et al., 2016). With a higher threshold, rural population estimates include primary sector workers based in small towns.

The c. 2010 results for the bin specification (eq. (2)) are shown in Table 3 (we consider both 2001 and 2012 for Niger). As can be seen, we tend to find stronger negative effects for rural populations than for total populations, especially when considering the 20K threshold. In other words, total population decline was likely driven by rural decline.[28]

Local Climate. 90 percent of rainfall comes from the evaporation of oceans, seas, and lakes (USGS, 2021a). In warmer climates, lakes also have a cooling effect on their direct environment. Therefore, when a large lake dries out, it permanently alters climate conditions. Lake Chad is an endorheic lake, meaning that it loses 100% of its water through evaporation. Thus, its shrinkage may have contributed to local climate change.

For each subdistrict-year, we know annual rainfall (mm) and average monthly temperature (Celsius) (see Web Data Appx. Section B for details). Focusing on the post-1950 period, we obtain for each subdistrict the mean of these measures in 13 five-year periods: 1950-1954, 1955-1959 ... 2010-2014. We then use the same panel bin specification as eq. (2) but use log mean annual rainfall or log mean monthly temperature as the dependent variable (we replace year dummies by period dummies). We then interact the three bin dummies with dummies for each period (omitting the interaction for 2010-2014). Lastly, as controls we include latitude and the Chari-Logone river dummies interacted with the year fixed effects, as well as the district trends.[29]

Table 4 reports the difference between the average effect for the full 1980-1994 period

[28]For Chad, the 0-150 km and 150-300 km effects are actually smaller for the rural population than for the total population, but the 300-450 km effect is larger for the former than for the latter.

[29]The exact model for subdistrict s and period t is: $ln(Climate)_{s,t} = \alpha + \sum_v \beta_{150,v} Lake_{150} \times \mathbb{1}(v = t) + \sum_v \beta_{300,v} Lake_{300} \times \mathbb{1}(v = t) + \sum_v \beta_{450,v} Lake_{450} \times \mathbb{1}(v = t) + \lambda_s + \theta_t + X_s B_{s,t} + District_s * t + \mu_{d,t}$.

and the average effect for the full 1950-1964 period.[30] Doing so allows us to capture long run changes in mean climatic conditions close to the lake post-1965.

As seen in Table 4, for rainfall we find significant negative effects. In particular, the elasticity goes from about -0.04 to -0.26 (hence -23%). In Niger, Cameroon, Nigeria, and Chad, we find rain losses of 4-8%, 5-23%, 9-16%, and 3-22%, respectively. As expected, we tend to find stronger effects for the subdistricts closest to the lake.

For temperature, we find significant positive effects in almost all cases. The elasticity goes from about -0.01 to 0.04 (hence +4%). In Niger, Cameroon, Nigeria, and Chad, we find temperature increases of 0-1%, 0-4%, 0-1%, and 0-1%, respectively. We also tend to find stronger effects for the subdistricts closest to the lake.

Given these are countries with low rainfall levels and very high temperatures already, these effects are meaningful.[31] In the model below, we will consider how such climate changes impact the different production sectors as well as amenities.

5. Model: Welfare Effects of the Shrinkage of Lake Chad

In this section, we develop a quantitative spatial model to study the local and aggregate welfare effects of the shrinkage of the lake and simulate the effects of different policies related to migration, trade, land use development, road construction, and cities.

5.1. Quantitative Spatial Model

We assume that there is a discrete set $\mathcal{N}$ of different locations (subdistricts) indexed by i and that workers operate in different sectors indexed by s. There are four different sectors in the economy: a fishing sector, an agricultural sector, a livestock sector, and an urban sector that captures both services and manufacturing. Following classic trade models, consumers have preferences in an upper nest for sectors and in a lower nest for varieties across locations àa la Armington . Consumers and firms face spatial frictions in terms of iceberg trade costs. The utility function in location i takes the following form:

$$U_i = \epsilon_{ij} \left(\frac{T_i}{\delta}\right)^{\delta} \prod_s \left(\frac{C_{is}}{\alpha_s}\right)^{\alpha_s}, \tag{3}$$

where T_i is land (housing), α_s is the expenditure share in goods from sector s and δ is the expenditure share in land or housing. We impose that $\sum_s \alpha_s + \delta = 1$. Next, ϵ_{ij} is an idiosyncratic shock that determines how much people are willing to migrate to other areas. Finally, C_{is} is a CES aggregator across locations that takes a standard CES form:

[30] For each bin, this corresponds to $(\beta_{1980-84} + \beta_{1985-89} + \beta_{1990-94})/3$ - $(\beta_{1950-54} + \beta_{1955-60} + \beta_{1960-64})/3$.

[31] In our sample of 452 subdistricts the mean of average monthly temperature in 1950-1964 was already reaching 27 Celsius degrees. The corresponding mean for New York City nowadays is 13 Celsius degrees.

$$C_{is} = \left(\sum_j c_{jis}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{4}$$

where c_{jis} are the quantities of variety j and sector s produced in location j and consumed in location i. In each location, there is a representative agent that supplies one unit of labor and is the owner of a per capita unit of water and land. Then, the indirect utility function takes the following form:

$$V_i = \frac{u_i(w_i + r_i t_i + q_i \tilde{w}_i)}{P_i},$$

where $P_i = \prod_s P_{is}^{\alpha_s}$ is the aggregate price index, $P_{is}^{1-\sigma} = \sum_j p_{jis}^{1-\sigma}$, $t_i = T_i/L_i$, w_i is the wage per efficiency unit, and $\tilde{w}_i = W_i/L_i$ is the number of land and water supply units per worker. Similarly, in each location and sector, there is a representative firm that faces an iceberg trade cost to move goods across locations. Each firm produces their own variety using the following Cobb-Douglas technology:

$$Y_{js} = A_{js} \left(\frac{L_{js}}{\beta_s} \right)^{\beta_s} \left(\frac{W_{js}}{\gamma_s} \right)^{\gamma_s} \left(\frac{T_{js}}{1 - \beta_s - \gamma_s} \right)^{1-\beta_s-\gamma_s}, \tag{5}$$

where A_{js} is the total factor productivity level, L_{js} corresponds to the number of efficiency units, W_{js} the amount of water consumed by firm j, and T_{js} the amount of land consumed, β_s is the input factor share or output elasticity with respect to labor in sector s, γ_s the output elasticity with respect to water supply, and $1 - \beta_s - \gamma_s$ the output elasticity with respect to land. For the three primary sectors we assume constant returns to scale. For the urban sector, we assume that there are additional agglomeration forces $A_{ju} = L_{ju}^{\mu}$, where μ captures the strength of the external economies of scale.

Given this setting and assuming perfect competition, the price of the good produced in location j and sold in i is equal to its marginal cost. Then,

$$p_{jis} = \frac{w_j^{\beta_s} q_j^{\gamma_s} r_j^{1-\beta_s-\gamma_s} \tau_{ji}}{A_{js}},$$

where τ is the traditional iceberg trade cost of moving goods from location j to location i, w_j is the wage per efficiency unit of labor in location j, q_j is the price of one unit of water, and r_j is the price of one unit land. Note that we are assuming perfectly competitive input markets in which there are no frictions to reallocate inputs across sectors.[32] For

[32]Following Lagakos and Waugh (2013) and Galle et al. (2021), this assumption could be relaxed by assuming an idiosyncratic shock drawn from an extreme value type distribution to move workers or other inputs across sectors. Relaxing the assumption would, if anything, increase the costs of the shock.

the inputs supply, we assume perfectly inelastic supply curves in each one of the input markets. Given this setting, the market clearing condition for each one of the input market in location j is given by the following expressions:

$$w_j L_j = \sum_s \beta_s \sum_i \frac{p_{jis}^{1-\sigma}}{\sum_l p_{lis}^{1-\sigma}} \alpha_{is} X_i \tag{6}$$

$$q_j W_j = \sum_s \gamma_s \sum_i \frac{p_{jis}^{1-\sigma}}{\sum_l p_{lis}^{1-\sigma}} \alpha_{is} X_i \tag{7}$$

$$r_j T_j = \sum_s (1 - \beta_s - \gamma_s) \sum_i \frac{p_{jis}^{1-\sigma}}{\sum_l p_{lis}^{1-\sigma}} \alpha_{is} X_i + \delta X_j \tag{8}$$

where X_i is the aggregate expenditure in location i. Imposing trade balances in the model, aggregate expenditure is equal to aggregate income, then:

$$X_i = w_i L_i + q_i W_i + r_i T_i.$$

We assume that the idiosyncratic shock ϵ_{ij} is drawn from a Nested Fréchet distribution with shape parameter η and location parameter u_i. The parameter η corresponds to the *migration elasticity*. When $\eta \to \infty$, we go back to the case in which workers are perfectly mobile across districts. Then the real income measure is equalized across locations. On the other hand, when $\mu \to 1$, the model replicates the specific factor model, and workers do not migrate across locations. Agents also face iceberg migration costs d_{ij} when they decide to migrate. From the properties of the Fréchet distribution, the share of people that migrate from location i to location j after an economic shock is given by:

$$\lambda_{ij} = \frac{u_j V_j^{\eta} d_{ij}^{-\eta}}{\sum_l u_l V_l^{\eta} d_{il}^{-\eta}}$$

where u_i is an *amenity parameter* that captures how attractive a location is conditional on real income. We model this parameter as $u_i = \bar{u}_i L_i^{-\lambda}$, where $\bar{u}_i$ is an exogenous amenity parameter of location i, and λ is the strength of the congestion force that prevents the multiplicity of equilibrium. Expected utility in the economy is given by:

$$\bar{U} = \left(\sum_i \left(\sum_l u_l V_l^{\eta} d_{il}^{-\eta} \right) \right)^{\frac{1}{\eta}}.$$

By the properties of the production and utility functions and assuming that $\mu < \delta + \lambda + \frac{1}{\eta}$ (i.e., agglomeration forces are lower than dispersion forces), an equilibrium exists and it is unique (Allen et al., 2015). The general equilibrium of the model is described by the following vector of endogenous variables:

$$x = \{w_i, q_i, r_i, P_{is}, L_{is}, W_{is}, T_{is}, T_{iH}, L_i\},$$

given a set of exogenous parameters:

$$A = \{A_{js}, \bar{u}_i, \alpha_{is}, \beta_s, \gamma_s, \delta, \sigma_s, \mu, \tau_{ij}\}$$

that solve the following system of equations: i) agents maximize their utility, ii) firms optimize their choice of inputs, iii) the price indices take the CES form, and iv) the market allocation solves the market clearing conditions from eq. (6) to eq. (8).

To calibrate the model, we use data c. 1965. Our quantification solves the model before and after the shrinkage of the lake. This is thus a static model that solves for the equilibrium in steady state. In our counterfactual we then compare two steady states: The market allocation in 1965 vs. what would have happened if the lake had not shrunk.

5.2. Calibration

As in the reduced-form analysis, we consider subdistricts as our model's locations. We then use different sources to calibrate the parameters of the model. More details on the parameters and sources used are provided in Web Appx. Section E.

Productivity scale parameters and initial endowments. We calibrate total factor productivity measures for the agricultural and livestock sector using information from the FGGD Digital Atlas of the FAO and IIASA. The atlas estimates the suitability of currently available land area for rainfed crops, using maximizsing crop and technology mix, as well as the suitability of currently available land for pasture. Using the data at the pixel level, we construct average indexes of agricultural suitability and pastoral suitability in each location, normalizing by the means in the aggregate data.

To generate variation across locations in the fishing sector, we assume a Heckscher-Ohlin mechanism in which fishing output depends on the initial endowment of quality-adjusted water in location i. First, we assume that all shore subdistricts have access to the full lake in 1965. Country boundaries were indeed not enforced on the lake's water.[33] However, most of the lake's open waters were located in the Southern and Western areas of the lake, giving Cameroon and Nigeria easier access to more productive waters. To obtain the relative productivity of each country and their shore subdistricts, we rely on Couty and Duran (1968) who provide estimates on the contributions of each country to the total fish caught (tons) in the area in 1960-61. We then know the share of each country in the lake's total perimeter (shore) and area (surface). This allows us to estimate

[33] Fisher people from Niger could for example get fish close to Chad's shore (Couty and Duran, 1968).

productivity ratios for each country. For a given lake area, Cameroonian subdistricts and Nigerian subdistricts are 160% and 80% more productive whereas Nigerien subdistricts and Chadian subdistricts are 10% and 50% less productive, respectively.[34]

We assume that coastal subdistricts in Cameroon and Nigeria have access to the full sea area within 13 km from the coast (restricting Cameroonian fisher people to Cameroonian waters and Nigerian fisher people to Nigerian waters). Indeed, the coastal fishing sector was dominated by small-craft fishing (NCMRED, 1968) and artisanal fishing units only operated up to 13 km from the coast in Nigeria (Aderounmu, 1986).[35] However, to obtain sea water supply in productivity-equivalent units of lake water supply, we use data on lake vs. sea fish production in both countries (sources: Chambre d'Agriculture (1965); NCMRED (1968)) and estimate that sea water is 20% and 100% more productive than lake water in Cameroon and Nigeria, respectively.

For the urban sector, we calibrate its TFP by using the population size of the largest city in the subdistrict normalized by total population in the subdistrict c. 1965 (since larger and more populated subdistricts may have mechanically larger cities).[36]

With all the location-specific productivity scale parameters A_{is} at hand, we are able to invert the model and recover the location-specific amenity parameters.[37]

Expenditure shares. We exploit various historical sources to reconstruct expenditure tables for each country c. 1965 and assume that α_{is} do not vary across locations within the same country. We then aggregate these numbers at the sector level (see Web Appx. Section E and Web Appx. Table C.4 for details). Ultimately, we use 0.35 for agriculture, 0.1 for fishing, 0.1 for livestock and 0.45 for urban. We then normalize these values such that the sum plus the expenditure share in housing adds up to one.

Input factor shares. These shares govern the production function technologies (Web Appx. Table C.5 reports the values used). For the agricultural sector, various studies find a land share (γ_s) of about 0.6, implying a labor share (β_s) of about 0.4.[38] For the livestock sector, Pellegrina (2022) estimate for Brazil a land share of 0.33 for agriculture and 0.53 for cattle, hence a difference of 0.2. In our case, the implied land share would be 0.6 + 0.2

[34] In other words, Chad has a lot of shoreline and lake area for a given level of lake fish production.

[35] Cameroonian fleets typically operate within 3.2 km from the coast (Ssentongo and Njock, 1987).

[36] We consider cities with 5K+ inhabitants for Cameroon (1965), Chad (1968) and Niger (1965). For Nigeria, we rely on cities with 10K+ inhabitants as reported by Africapolis (2021) for the year 1960.

[37] We recover the vector of amenities by perfectly matching the spatial distribution of the population implied by the model with the one from the data. Specifically, we solve for the real income measures, and then we solve a system of equations such that the amenities match the model with the data.

[38] Weil and Wilde (2009) consider a land share of 0.57 for sub-Saharan Africa, whereas Chen et al. (2017a) find a share of 0.58 for Malawi, which Restuccia and Santaeulalia-Llopis (2015) also assume for Ethiopia. Gollin and Udry (2021) find 0.61 for Tanzania and 0.53 for Uganda. Finally, using the estimates from Avila et al. (2010), we obtain an average share of 0.56 for our four sample countries in 1961-1980.

= 0.8. If we use estimates from Avila et al. (2010), we obtain an average land share of 0.55 for our four sample countries in 1961-1980. However, it is unclear how Avila et al. (2010) obtain their estimates for our four countries. We thus consider a more intermediary land share of 0.7 in the livestock sector (and a labor share of 0.3). Also note that we assume that the lake's water is not directly used as an input in both sectors.

There are no available estimates for the mostly artisanal fishing sector in sub-Saharan Africa. However, it is likely that fishing is as "land-intensive" as the livestock sector, except for the fact that "land" in this case is fishing (lake or sea) water. We thus consider a water share of 0.7, implying a labor share of 0.3 (and a land share of 0).

For the urban sector, Ahlfeldt et al. (2015) use a land share of 0.2 based on findings from Valentinyi and Herrendorf (2008). In contrast, Hsieh and Klenow (2009) use a labor share of 0.3 for manufacturing and services. We take a weighted average between these two inputs and use an intermediary value of 0.3 for the urban land share, implying a labor share of 0.7. Note that we purposedly ignore capital in the four sectors because these countries' economies were not capital intensive c. 1965. Furthermore, capital is implicitly included in labor in our analysis. Indeed, while land and water are spatially fixed, we assume that if there is any capital it is proportional to labor and "moves".[39]

Elasticities. For the main elasticities, we use the findings from different studies. Web Appx. Table C.6 shows the main parameters and the values assigned to them.

In particular, we assume a migration elasticity of 2 based on the recent evidence from Monte et al. (2018) in the United States. For the trade elasticity, we follow Donaldson (2018) and use 4 for the primary sectors, whereas we use 1 for the urban sector based on recent evidence by Boehm et al. (2020) that estimate long-run trade elasticities in the manufacturing sector. For the congestion force, we simulate the model considering two different values: 0 and 0.32, the value obtained by Desmet et al. (2018). For the agglomeration force, we assume a conservative value of 0.1 that previous studies have used in more developed economies (Ahlfeldt et al., 2015; Bartelme et al., 2019).

Finally, to calculate the trade costs across locations, we rely on the historical road quality database from Jedwab and Storeygard (2021).[40] We follow their methodology by constructing a grid of 0.1*0.1 degree ($\approx$ 11*11 km) cells and assigning to each cell a different travel time based on the best road quality in the cell c. 1965 (using the speeds

[39]Our results are robust to different land and labor share values in the urban sector. We ran the simulations using a value between 0.2 and 0.5 for the land share. Results are available upon request.

[40]Nelson and Deichmann (2004) provide road locations for all of Africa. Using these road locations as a baseline, Jedwab and Storeygard (2021) digitized 64 Michelin road maps produced between 1961 and 2014 to represent contemporary road conditions for the whole continent. More precisely, they distinguish *highways, other paved roads, improved roads* (laterite or gravel), and *dirt roads*.

they implemented for each road quality). We also include a boat transportation mode through the lake to capture the fact that trade costs can increase due to the shrinkage of the lake. Within a context of high road costs, the lake was particularly important to trade in the area (Magrin et al., 2015). We also assume border costs that imply goods can only be transported through certain border cities.[41] Next, Web Appx. Fig. C.5 plots the full distribution of travel times for all subdistricts within 300 km of the lake *before* and *after* the shock. As expected, we observe an increase in travel times since economic agents now must move goods around the lake by road instead of using the lake itself.

Finally, to transform the travel times between subdistricts into trade costs, we assume the same functional form as in Sotelo (2020) and Baldomero-Quintana (2021):

$$\tau_{ijs} = \exp(\delta * t_{ij})(1 + \text{tariff}_{ijs})$$

where t_{ij} is the travel time between locations i and j, δ is the parameter that transforms travel times into trade costs, and tariff_{ijs} is a tariff of 20% if locations i and j are in different countries.[42] We estimate δ using information from: (i) the average price of "imported goods" for 48 Cameroonian cities in 1965 (source: Marguera (1975)); and (ii) the price of imported oil for 19 Nigerien cities in 1962 (source: Commissariat Général au Plan (n.d.)). Since, within a country the goods are homogeneous and have the same point of entry, differences in local prices should reflect differences in trade costs. Using the fact that the model implies that $p_{ijs} = \tau_{ijs} p_{js}(1+\text{tariff}_{ijs}) = \exp(\delta t_{ij}) p_j (1+\text{tariff}_{ijs})$, we estimate δ by running a regression within Cameroon and Niger relating the prices to travel times.[43] We obtain a δ of about 0.08, which is similar to the ones obtained in the literature. Web Appx. Section. F explains in more detail this procedure.

Finally, we invert the model and recover an amenity distribution for each location by matching the population in the data with the one from the model. By design, the model perfectly fits the data in terms of population distribution across space.

5.3. The Shock(s) and Simulation Results

We run a counterfactual that considers separate sub-shocks due to the main shock:

We run a counterfactual that considers separate sub-shocks due to the main shock:

1. *Transportation sub-shock:* Trade costs increase since some economic agents cannot use the lake anymore to transport goods across it.
2. *Fishing sub-shock:* There is a reduction of around 95% in the total area of the lake. In 1965, thirteen subdistricts had access to the lake. In 2010, only three subdistricts

[41] See Web Appx. Fig. C.6 for more details on the selected border cities.
[42] of Commerce et al. (1962) writes that tariffs were on average 20% in Nigeria in 1962.
[43] Since we estimate this regression within each country, we ignore tariffs.

still have access to the lake (two in Chad, one in Cameroon). We assume that all locations that lost access to the lake experience a 100% decline in water supply. The locations that still have access experience a 95% loss in water supply and an additional productivity loss of 50% in the remaining lake area, hence a 97.5% loss in quality-adjusted water supply. This shrinkage has been associated with high ambient temperatures, low dissolved oxygen and the disappearance of spawning places and/or shelter for young fishes (Carmouze et al., 1983; Raji, 1993). As a result, fish stocks in the remaining waters decreased. In the absence of clear data on these effects, we assume a 50% loss.

3. *Agriculture and livestock sub-shocks:* We also model a productivity shock in the agricultural and livestock sectors that consists of four components:

    (a) *Land supply effect:* Productivity increases in the areas where the lake dried out since land becomes available and the average agricultural and pastoral suitability of the affected subdistricts increase. For newly available land for which suitability is not known (FGGD does not report any estimate for the pixels within the former lake areas), we assign to the affected pixels the value of the closest cell that is outside the lake and has a strictly positive value. As such, the magnitude of this positive effect depends on land quality in the area. However, it also depends on the establishment of property rights and land markets as well as infrastructure development in the former lake areas. We do not have localized data on these dimensions, but we can use satellite-based data on population patterns c. 2015 (source: Florczyk et al. (2019); resolution: 0.0025*0.0025 degree) to obtain for each country a "development rate" inside the former lake areas relative to just outside the lake areas. We obtain 6.9%, 14.6%, 3.7% and 3.4% for Cameroon, Chad, Niger, and Nigeria, respectively. Thus, the former lake areas are still largely undeveloped today. [44] Finally, we weigh each subdistrict's suitability by the country's development rate.[45]

    (b) *Irrigation effect:* Productivity decreases by 50% for pixels within a 20 km range from the lake boundary. The goal is to capture the impact of losing access to irrigation since the World Bank reports that irrigation can double productivity.[46] We then use 20 km because irrigation is mostly small-scale in

[44]More precisely, we compare the share of pixels with at least some population inside vs. outside the lake. 100% would imply that the former lake areas are as "occupied" overall as the areas outside the lake.

[45]Note that we use the country's development rate rather than a subdistrict-specific development rate as the latter is endogenous to local conditions, which we want to avoid in order to calibrate the model.

[46]The World Bank writes: "Irrigated agriculture is, on average, at least twice as productive per unit of land as rainfed agriculture." See https://www.worldbank.org/en/topic/water-in-agriculture#1. Likewise, Fuglie (2008) finds that rainfed land is two times less productive than irrigated land on average. In Africa,

the lake area, which limits how far land can be irrigated.[47] With the shore of the lake retreating, existing irrigation networks becomes obsolete.

(c) *Species extinction effect:* The lake's drying led to the extinction of species that were particularly adapted to the lake's environs. One such species is the Kuri cattle breed. Mpofu and Rege (2002) writes: The "importance of the Kuri lies not only in its unique physical characteristics but also in its meat and milk production potentials. The breed is so acclimatized to the environs of Lake Chad that it is unable to survive elsewhere." While there were 200,000 heads of Kuri cattle in 1972, there were only 10,000 heads left in 2002, implying an extinction rate of 95%. Importantly, the Kuri breed has a daily milk yield that is two times greater than other cattle breeds in the area (Santoze and Gicheha, 2018). From the website of the Animal Genetics Training Resource center,[48] we obtain a map of which subdistricts had Kuri cattle. From various sources, we obtain the total number of cattle heads in the Lake Chad region c. 1965, thus the share of the Kuri breed in that total (about 4%).[49] An extinction rate of 95% implies a cattle production loss of close to 7%. Since cattle accounted for 87% of total livestock units (TLUs) in the four countries in 1965 (FAO, 2021),[50] the livestock productivity loss was about 6% for each subdistrict with Kuris.

(d) *Local climate change effect:* We assume that productivity decreases in both the agricultural and livestock sectors within a 450km range of the lake due to local climate change – temperature increases and rainfall decreases – caused by the lake's shrinkage. First of all, from various studies, we know the relationship between the yields of the main food crops in the area – millet and sorghum – and temperatures as well as rainfall.[51] Second, we know the relationship between rainfall levels and the production of total dry matter (TDM), i.e. total herbaceous forage productivity, or vegetation that can be used to feed livestock.[52] We also know the relationship between

yields on irrigated fields are 90% higher on average than on nearby rainfed fields (Fuglie and Rada, 2013).

[47]The main type of irrigation in the area is surface irrigation. Farming, for example, is done in "polder" depressions, i.e. interdunal valleys, around the lake (Evans and Mohieldeen, 2002; Luxereau et al., 2012). Water is brought there using traditional irrigation techniques (e.g., dense and deep networks of man-made furrows). When small dams and pumps are used, the water can be brought past the polders.

[48]Url: http://agtr.ilri.cgiar.org/kuri, accessed 11-07-2021.

[49]See Web Appx. Section E for details on the sources used.

[50]TLUs are a unit used by the FAO to aggregate livestock species on each species' standard weight.

[51]Sultan et al. (2013) exploit rainfall anomalies in West Africa's savannas, in other words in similar geographical conditions as in the lake area, finding that yields decrease by 0.67% for each percentage decrease in rainfall. For the effect of higher temperatures, we rely on Knox et al. (2012) who estimate for West Africa the mean yield change across all crops (-12.5%) due to future climate change (+1.4^{o}C). They find similar losses for millet and sorghum. Thus, yields decrease by 8.9% for each ^{o}C increase.

[52]For West Africa today, Leeuw and Tothill (1990) finds the following relationship between TDM and

> temperature increases and body weight loss (i.e., meat and dairy production) in the livestock sector.[53] As showed before, we know the percentage decrease in rainfall and percentage increase in temperature for each subdistrict within 450 km from the lake. We then calculate the absolute change experienced by each subdistrict, and the corresponding productivity decreases.

Figures 7 to 9 plot the distribution of the subshocks across locations. To model the productivity changes, we sum up the different components instead of interacting them. However, we do not know how the subshocks interact. If the interacted effects are negative, we should under-estimate the negative effects of the overall shock.

Figure 7 shows the total shock for agriculture. Productivity decreases on average by 25% for the areas close to the lake (subfigure (e)). There is however one small location that experiences a considerable productivity gain due to new land becoming available. Yet, the land supply effect appears small overall since most of the land around the lake is not very valuable. As a result, many cells only see a small increase in suitability, especially in Chad where land close to the lake is arid. In addition, many former lake areas remain underdeveloped today, likely due to incomplete property rights, lacking infrastructure, security issues, etc. (Batello et al., 2004).[54] In one of our policy scenarios, we simulate the effects of policies removing such constraints on land use development.

Figure 8 show the shock for the livestock sector. Lake productivity decreases by about 20% on average in the areas close to the lake. Two small locations experience a major increase in their pastoral suitability because land becomes available.

Finally, figure 9 plots the most important shock in the model, which is the loss of water for the fishing sector. Ten subdistricts completely lose access to the lake (loss of 100%), while three subdistricts experience a productivity loss of about 80%.

5.4. Counterfactuals

Table 5 reports the aggregate economic losses for different values of the congestion force (-0.32 as in Desmet et al. (2018), or 0 for comparison). On average, aggregate welfare losses (col. (5)) are between 4% and 9% depending on the migration scenario, i.e. how much we allow populations to move across locations when faced with the shock. We consider six scenarios: (i) *Free migration* across all locations; (ii) *Migration*

---

rainfall (mm): TDM = 0.05 + 0.0027 *rainfall. The relationship is particularly linear.

[53] Seo and Mendelsohn (2008) estimate the impact of future climate change, i.e. higher temperatures, on total income of the livestock sector in sub-Saharan Africa. Using their results, we calculate that income from livestock should decrease by 11.5% for each ^{o}C increase.

[54] Batello et al. (2004) writes: "As a result, although there is great potential for increasing food production in the Lake Chad Basin, most of the production is still for household consumption, and only a small portion of the cereals produced in the area reaches the marketplace."

Cameroon-Chad-Niger: The residents of these three former French colonies do not move to Nigeria, a former British colony, for example due to linguistic differences. The residents of Nigeria can only move to other locations in Nigeria; (iii) *Migration within countries*: Borders are closed; (iv) *Migration within regions*: Residents can only move to other locations in the same region;[55] (v) *Migration within ethnic groups*: Residents can only move to other locations belonging to the same ethnic homeland, even if the location is in a different country; and (vi) *No migration*: Residents cannot move.

Aggregate losses. We find an aggregate loss of 4% in the case in which there is free migration vs. 7-8% in the other migration scenarios (see column (1)). Similar to Desmet et al. (2018), we find more significant losses in the counterfactual in which workers cannot easily migrate across locations. When some locations become less productive in some sectors, total production in these sectors is less impacted if labor can move to other locations where production can still take place. Next, in all scenarios, Chad is the most affected country. This can also be observed by comparing the mean loss across the six scenarios (see last row of each panel: 12.8% for Chad, 7.0% for Niger, and 5.3% for both Cameroon and Nigeria). This is partially due to more of Chad's subdistricts losing access to the lake's water, disproportionately impacting Chad's fishing sector. Cameroon and Nigeria are also impacted but their coastal subdistricts still have access to the sea[56]

Interestingly, the aggregate effects are not that different across the five other scenarios, from the less restrictive Cameroon-Chad-Niger scenario to the most restrictive no-migration scenario. That is not necessarily what we would have expected, given that migration improves the adaptation capacity of hardly hit sectors, for example by increasing production in less affected locations. But there is also a migration-induced congestion effect. The aggregate loss is higher in the within-migration scenario than in the no-migration scenario, likely because many agents move to richer, less-impacted locations. In other words, when there is only migration within countries, the congestion externalities are so large that some of the richer locations in each country end up losing more than in the no-migration scenario.[57] Indeed, without the congestion force (see Panel B), the aggregate loss tends to decrease (mean across the six scenarios of 5.9% vs. 7.1% before). Furthermore, when there is no congestion force, the gap between the no- and within-migration scenarios increases compared to the congestion case

[55] We use broad regional boundaries c. 1965. There are 6, 9, 7 and 4 such regions in Cameroon (pre-1960), Chad (1955), Niger (1964) and Nigeria (1961), respectively. These regions correspond to regional labor markets whose subdistricts likely share common ethno-linguistic and religious traits.

[56] There are other factors as well. For example, the land supply effect is likely small in Chad because of the higher aridity of its land around the lake. This renders the land less usable which we then use to impute land quality in the former lake areas. Chad also experiences large rainfall losses.

[57] Some of the agglomeration effects are also not realized when some agents migrate to other rural areas in other countries instead of urban areas in the same country.

(from 8.4-8.7 = -0.3% to 9.2-4.5 = 4.7%), mostly due to the much lower loss associated with the within-migration scenario (4.5 vs. 8.7 before).

Relatedly, when we compare the effects across countries (cols. (2)-(5)), the country that is the most affected is Chad, generating losses between 8% to 15%. As migration costs decrease, Chad tends to benefit more relative to the other countries, because it can "send away" many of its impacted agents to other countries, which then experience a larger congestion effect. For instance, Nigeria – the richest country in our analysis – experiences larger losses under a free migration scenario (3.8%) than in the case in which there is only migration within countries (3.2%). Likewise, if migrants from Chad and Niger cannot move to Nigeria but can move to the second richest country in our analysis Cameroon, as in the Cameroon-Chad-Niger scenario, losses increase for Cameroon (we find 6.7% in the former scenario vs. 4.2% in the free migration scenario).

Finally, we perform a simple cost-benefit analysis to understand the effects of the Transaqua project that proposes to construct a 2,400-km canal aimed at diverting enough water from the Congo River Basin in the Democratic Republic of the Congo in order to replenish Lake Chad. The cost of the project is estimated at US$50 billion (Sayan et al., 2020; The Conversation, 2021). Using today's GDP numbers and the aggregate economic losses we find, the total benefit of the project in the worst-case scenario (no migration) would be about US$38 billion, implying that it would only cover 75% of the total cost. Of course, were we to use a better-case scenario and/or the four countries' GDP numbers in 1965, the Transaqua project would be even less worth it.

Spatial distribution of the welfare effects. Figure 10 plots the change in welfare by subdistrict in our baseline counterfactuals. Panel (a) shows the results for no-migration scenario, panel (b) the case in which there is migration within ethnic groups, panel (c) within country-regions, panel (d) within countries, panel (e) when there is free migration between Chad, Cameroon and Niger, and panel (f) free migration.

Overall, the map shows that the subdistricts in which the lake shrunk are the areas where economic losses are the largest. For instance, some of these regions experienced losses larger than 50% in terms of real income. Similarly, we can observe that Chad and Niger are the most impacted countries, while some regions closer to the sea in Nigeria and Cameroon experience some positive gains since they still have access to water to produce fish after the shock. The figures also show that people would try to move to the coastal and Southern areas of Nigeria and Cameroon after the shock, and that the losses for Chad are much smaller when there is free migration across countries.

More generally, comparing the five maps, the results suggest that when there is a decrease in migration costs, the distribution of welfare losses is less heterogeneous across space. For example, in the no-migration case, the regions that directly experience the shock suffer losses larger than 90%. In some coastal regions in Nigeria and Cameroon, gains are higher than 10%. On the other hand, with free migration, the regions that directly experience the shock only suffer losses of around 70%, and the coastal regions of Nigeria and Cameroon experience lower gains of around 5%.

Spatial distribution of the population effects. Figure 11 plots the post-shock changes in population across subdistricts. By construction, population does not change in the no-migration case (the panel (a) of the previous figure). We thus focus on panels (b)-(f). Panel (b) shows the results for the case in which there is migration within ethnic groups, panel (c) migration within country-regions, panel (d) migration within countries, panel (e) migration between Chad, Cameroon, and Niger, and panel (f) free migration.

We can observe that the different counterfactuals lead to different patterns of population across space. In the case where there is only migration within countries ((c)), most of the affected population in Chad will migrate to the Eastern regions of Chad (likewise to the Western regions in Niger). While in the case where workers can freely migrate across countries, most of the population will reallocate to the Southern areas of Nigeria and Cameroon, and even some of Chad's population that did not directly experience the shock (in Chad's Eastern areas) will migrate to these countries. We can also see that since congestion forces are higher than agglomeration forces, as people migrate to a region the losses (gains) from the shock are larger (smaller).

Summary. Overall, the results suggest significant economic losses from the shock. While the biggest "losers" are the areas close to the lake, most subdistricts experience economic losses in terms of real income. For example, prices in the three primary sectors increase. Nonetheless, a few coastal subdistricts in Nigeria and Cameroon experience positive gains. Similarly, there is enormous heterogeneity in the welfare impacts of the shock, which suggests that climate change may increase real income inequality across locations. Moreover, in terms of policy, the results imply that it is important for countries to coordinate migration policies. For instance, losses are much smaller in a world without migration costs. Furthermore, governments must tackle other issues such as rivalry between ethnic groups and facilitate internal migration. In the next section, we link the model to the reduced form estimates of Section 3..

5.5. Population Elasticities and Data Moments

We compare the results of the model with the reduced form estimates of the first part of the paper to see how good the fit of the model is with respect to the previous findings. Using simulated data from the model, we estimate the following specification:

$$\Delta \ln y_i = \gamma_0 + \beta_1 \cdot (-\ln dist_i) + \gamma_{c(i)} + \epsilon_i, \tag{9}$$

where $\Delta \ln y_i$ corresponds to the change in population of subdistrict i after the shock, $dist_i$ is distance to the lake, and $\gamma_{c(i)}$ are country fixed effects. Our parameter of interest is β_1. We also estimate a specific coefficient for each country. This regression replicates the panel-DiD specification from the empirical section 3.. One important caveat is that the model assumes full employment and that the aggregate population is fixed. Thus, we would not capture differential changes in mortality rates due to the shock or migration from/to other countries in sub-Saharan Africa and the rest of the World.

Furthermore, there are other effects that may have taken place in real life but are not included in our model. As explained above, we do not consider the negative interacted effects of the different subshocks. We also ignore the effects of the lake's shrinkage on some amenities, for example access to drinking water. Lastly, income losses around the lake may have caused conflict, which may have in turn further reduced incomes. Therefore, we expect to obtain smaller coefficients in the regressions with the simulated data than the ones obtained in the reduced-form framework.

Table 6 reports the results. Panel (a) shows the free-migration scenario whereas panel (c) shows the within-country migration. On average, we find an elasticity of population with respect to distance to the lake of around -0.25. This coefficient is one third smaller than the one found in the empirical section (we found -0.38 circa 2010). In other words, our model potentially captures two-thirds of the overall shock, which is, in our view, a promising result. The remaining third could then be due to omitted subshocks such as differential mortality rates due to the lake, the negative interacted effects of the subshocks, amenities, and feedback effects such as conflict poverty traps.

However, the model replicates well that locations close to the lake experience larger losses. Moreover, if we compare the country-specific elasticities, we find patterns that are broadly consistent with what we had found in our reduced-form framework. For Chad, the coefficient is around -0.43, explaining 70% of the effects we find in the empirical section (-0.62). For the other countries, we find coefficients around 0.13-0.16, explaining about 40% of the shock in Cameroon and Nigeria, and 50% in Niger.

Moreover, we try to match other moments of the data to show that the fit of the model is good. Figure 12 plots a scatter plot between the aggregate GDP shares that we compute at the baseline equilibrium using the model vs. the GDP shares by country-sector c. 1965.[58] Each dot represents a country-sector observation. Overall, the model does a very good job matching the data for different values of the trade elasticities and the labor share in the urban sector, since we are less sure about these parameters than other parameters. For example, we have found more relevant evidence on the land share

[58]See Web Appx. Section E for details on the sources for the c. 1965 GDP shares.

in the agricultural sector, which makes us more confident about this parameter.

Panel (a) shows the relationship between the model and the data for a labor share of 0.7 (baseline), and panel (b) for a labor share of 0.5. We then consider two scenarios for the trade elasticities: 4 (i.e., 5-1) for the three primary sectors and 1 (i.e., 2-1) for the urban sector in our baseline calibration vs. 3 (i.e., 4-1) for the three primary sectors and 2 (i.e., 3-1) for the urban sector. The figure shows that the fit of the model is very good. For instance the point estimate of the linear fit is around 0.8 for the different specifications and the R-squared is also 0.8. Similarly, the differences between the GDP shares is less than 10% for almost all the country-sector observations and the average difference between the model and and actual GDP shares is about 5-7% only.

5.6. Policy Simulations

We simulate fifteen different policies to understand the role of various interventions to mitigate the adverse effects of the shrinkage of Lake Chad. We divide these policies into four distinct subgroups: *land development* policies, which focus on property rights as well as infrastructure development in areas with newly available land; *trade liberalization*, which reduces tariffs; *road construction*, and the *absorption capacity* of locations and cities in particular, hence congestion and agglomeration externalities.

To calculate how much these policies reduce the effects from the lake's shrinkage, we must ignore the positive individual effect of the policy itself. To do so, we simulate the policy's impact two times, first before the lake's shrinkage, and then after it. Next, we obtain the difference in the impact between the two, which captures how differentially important the policy is in the post-shock economy. We then compare the differential impact across 15 policies and 5 migration scenarios (ignoring the "migration within ethnic groups" scenario). Table 7 shows the aggregate effects across the four countries. Table 8 shows the results if we only consider the Lake Chad region, i.e. the subdistricts located within 450 km from the lake. Indeed, a social planner concerned about spatial inequality may want to consider the Lake Chad region's losses specifically.

Migration. Row 1 shows for each migration scenario the aggregate loss across the four countries. Row 2 shows the positive effect of reducing migration costs relative to the no-migration scenario. As before, the aggregate loss is the lowest in the free migration scenario (about 4%; Table 7). The loss is then quite stable around 7-8% in the four migration cases. Overall, we find that lowering migration frictions mitigates the impact of the shock, except for the case in which there is only within-country migration (the loss is 8.72% vs. 7.17% when there is only migration within country-regions). This result is explained by the fact that some regions in Chad and Niger where people migrate after the shock (in the West of Chad and East of Niger, respectively) experience more considerable losses due to congestion forces. On the other hand, the findings imply that the Lake Chad region always mitigates the shock as migration frictions decrease since they can migrate to other regions (Table 8). These policies would greatly benefit the area since congestion forces are larger than agglomeration externalities.

Next, rows 3-18 show the mostly positive effects of implementing each policy. Each cell corresponds to the percentage points by which the policy mitigates losses.

Land development. The first set of policies (*land development*; rows 3-6) consists of establishing clear property rights, facilitating the creation of land markets, ensuring safety and providing a minimal level of infrastructure to develop the land that becomes available due to the lake's shrinkage. We simulate four policies. The first one consists of raising the development rate to the maximal value observed across the four countries (which is 15%) (row 3). In the other simulations, we raise this rate to 25% (row 4), 50% (row 5) and 100% (row 6), respectively. The results suggest that land policies would have a negligible impact overall. The aggregate impacts are only between -0.03 and 0.03 p.p., and the effects in the Lake Chad region are less than 0.12 p.p. across the various migration scenarios. Of course, the effect is higher with the highest development rate (100%). This finding suggests that land development policies in the region would be mostly ineffective. The reason for this result is that even though new land becomes available, the quality of this land is not very high. That might be a specific feature of our context, where Lake Chad was located in a mostly arid region. To some extent, this made the lake more crucial to local populations. In other contexts where lakes are located in cooler climates and surrounded by better land overall, the land supply effect could be larger. However, the fact that lakes have positive effects on the local climate, thus land productivity in the environs, suggests that the increasing disappearance of lakes is not a phenomenon that we may want to encourage in order obtain more land.

Road construction. In the second and third set of policies, we simulate a reduction in trade costs. In the second set (rows 7-12), we recalculate the travel times between the various subdistricts after the Government paves roads that were unpaved before. In the first subset, the budget of the Government is country-specific, and in the other subset, countries have the same budget. We first simulate a policy that paves the (as of 1965) unpaved ring road around the lake (Web Appx. Fig. C.7).[59] 83 cells are paved in total, including 45 in Chad, 19 in Nigeria, 10 in Niger and 9 in Cameroon. 83 cells to be paved is thus the budget that we use for our simulations. Note that it corresponds to 8% of the total paved network as of 1965. For the country-specific budgets, we then use 45

[59] To define the ring road, we study the 1965 Michelin map. The map indicates if a road is transcontinental or important. We use this information to select some road segments, i.e. cells. For the remaining road segments, we select the cells whose paving minimizes the travel time around the lake.

cells in Chad, 19 in Nigeria, 10 in Niger and 9 in Cameroon. For the same budget cases, we use $83 \div 4 \approx 21$ cells in each country. Since Chad has more lake shoreline than the other countries, it would make sense that Chad receives more road funding from say the international community. But the international community may also want to treat each country equally, in which case each country would receive the same budget.

As shown in Web Appx. Fig. C.7, we consider three policies for each bugdet case, hence six policies in total: (i) "Around the lake": Note that in the same budget case, we select for each country the closest ring and non-ring road cells to the lake; (ii) "Lake-to-cities": We pave the unpaved cells of the fastest road from the lake to the country's largest city as of 1965.[60]; and (iii) "Cities-to-lake": We pave the unpaved cells of the fastest road from the country's largest city to the lake. Since the largest cities typically already had paved roads around them c. 1965, this leads us in some cases to pave roads located in more intermediary regions between the largest city and the lake.

On average, these policies have a significant impact in reducing the aggregate losses due to the shock. This impact is higher as migration frictions increase. For example, in the within-country migration case, building new roads reduces the effects between 0.6 and 1.0 p.p. In the free migration scenario, losses are reduced by 0.1-0.2 p.p. only (see Table 7). Next, when we compare the effects across the different policies, we find that the "cities-to-lake" policy is more impactful, especially with migration frictions (e.g., 0.7-1.0 p.p. in the within-country migration case). The effects are smaller for the "around the lake" and lake-to-cities" policies (0.6-0.7 p.p. in the same case). This comes from the fact that the receiving locations in the "cities-to-lake" policy are richer subdistricts on average in our baseline equilibrium. We then do not find significant differences overall between the same budget and specific budget case.[61]

Focusing on the Lake Chad region only (see Table 8), the estimated effects are even higher. Interestingly, road construction from the largest city to the lake is more beneficial to the lake locations than road construction from the lake to the largest city or road construction around the lake. For example, in the within-country migration and same budget scenario, we get 1.7 p.p. in the former case vs. 1.2-1.4 p.p. in the latter cases.

Trade. The third set of policies consists of a trade liberalization episode that can affect the four sectors differently. We first reduce tariffs from 20% to 10% across all goods (row 13). For the tariff reduction, we then only consider the three primary sectors (agriculture, livestock and fishing) (row 14) or the urban sector (row 15).

[60] We also prioritize roads indicated as transcontinental or important in the 1965 Michelin map.

[61] However, the "cities-to-lake" policy has a larger effect with the same budget rather than country-specific budgets. Indeed, a same budget for each country increases the amount of paving in Nigeria and Cameroon, our two richest countries. The effects of road construction then increase.

Overall, policies that reduce trade costs have a large impact on mitigating the effects of the shock, especially when there are migration frictions. Trade is an important margin of adjustment when workers cannot move across countries. In that case, the "lost" production of some sectors in some countries has to be made up for by increased production in other countries and trade. For instance, a tariff reduction of 10 p.p. across all sectors reduce aggregate losses by 0.5-1.0 p.p. when there are migration frictions (see row 13 of Table 7). When we compare the effect across policies (rows 14-15), a tariff reduction in the urban sector tends to generate slightly larger gains than when implemented in the primary sectors. That might be surprising given that the lake's drying is mostly impacting the primary sectors, whose prices increase after the shock. However, when urban trade liberalizes, the largest and most productive cities grow even more (since their locations specialize even more in their comparative advantage, which is in urban goods). As a result, more people move to richer areas and stronger agglomeration economies are realized. Of course, there is also a congestion externality but this effect is taking place regardless of whether people move to large cities or productive rural areas (which do not experience agglomeration externalities).

As before, the effects are larger in the Lake Chad region (Table 8). Ignoring the no-migration scenario for which the effects are very large, the patterns in terms of whether one should liberalize trade in the primary sectors or in the urban sector are now less clear. Indeed, the ranking of these two trade policies depend on which migration scenario is more realistic in the four countries (e.g., country-regions vs. within-country).

Absorption capacity. The last set of policies reduces the congestion externality, which affects all locations, and increases the agglomeration externality, which only affects the urban sector. Although the Government cannot directly affect these parameters, we want to simulate policies raising the capacity of non-directly impacted locations to absorb migrants from the Lake Chad region. We also want to analyze the effects of increasing the positive effects of urbanization, in particular through agglomeration economies. In row 16, we reduce the congestion externality from -0.32 to -0.20 (37% reduction). In row 17, we double the agglomeration externality from 0.10 to 0.20.

The findings imply that reducing the congestion force would also significantly reduce losses (row 16 of Table 7), especially in the within-country migration scenario. In that scenario, migrants from the Lake Chad region move to already developed, and congested, locations in their own country, which increases congestion effects in the aggregate. With free migration, they can instead spread across many locations in the four countries. With the no-migration case, they cannot migrate to other locations. Thus, there is an inverted-U relationship between losses and the level of migration frictions. Results then differ if we focus on the Lake Chad region (Table 8). In that case, losses tend to increase with migration frictions, because the Lake Chad region cannot send away its migrants to other locations. Losses are then worse in the within-country-regions migration scenario than in the no-migration scenario because a lot of people end up in a few locations in their own region, dramatically increasing congestion.

Finally, increasing the agglomeration force in the urban sector (row 17 of Table 7) does not substantially mitigate the adverse effects of the shock. Indeed, we do not find that the countries' urban share increase, or decrease, as a result of the shock. Agglomeration effects are thus not that different in the economy before the shock hits vs. after it does, making the differential effect small. However, we see a larger effect of the agglomeration policy when focusing on the Lake Chad region (Table 8) and the within-country-regions migration scenario. If rural migrants cannot move to other rural areas in the rest of the country or across the four countries, they may have to move to urban areas in their own region. Then the agglomeration policy becomes more consequential.

6. Concluding Discussion

Despite an extensive literature on the economic consequences of climate change, the past economic effects of climate change as defined by the IPCC, and diminishing lakes in particular, have to our knowledge not been widely investigated.

We thus focused on Lake Chad, historically the 11th largest lake in the world and which lost 90% of its surface area between 1965 and 1990. For Cameroon, Chad, Niger and Nigeria, hence 25% of sub-Saharan Africa's total population today, we constructed a novel data set tracking total population patterns at a fine spatial level from the 1940s to the 2010s. We then exploited a panel difference-in-difference strategy to estimate the effects of the lake's shrinkage on nearby communities. We found slower total population growth in the proximity of the lake, despite the fact that the lake's shrinkage increased land supply. We did not find evidence for population recovery in the long run. We also found negative effects of the lake shrinking on local climatic conditions.

We then used a quantitative spatial model to show that the shrinkage of the lake had large negative local and aggregate welfare effects. We then used the model to discuss the effects of various policies related to migration, trade, land use, roads, and cities.

More generally, while our work cannot fully answer the question of how governments should respond to climate change, and shrinking lakes in particular, our results suggest that such natural disasters could have permanent negative economic effects in poor agrarian economies. In such countries, rural decline is likely to increase migration. Unless governments and the international community find ways to reverse changes due to such natural disasters, which in this case could imply diverting other rivers regionally or stopping climate change globally, the shrinkage of lakes is likely to increase already existing pressures on poorer economies, especially in sub-Saharan Africa.

REFERENCES

Aderounmu, AA, “Small-scale fisheries development in Nigeria: Status, prospects, constraints/recommended solutions,” 1986.

Africapolis, *Africapolis City Population Database*, Paris, France., 2021.

Ahlfeldt, Gabriel M., Stephen J. Redding, Daniel M. Sturm, and Nikolaus Wolf, “The Economics of Density: Evidence From the Berlin Wall,” *Econometrica*, November 2015, *83*, 2127–2189.

Ahmad, Ehtisham and Raju J. Singh, *Political Economy of Oil-Revenue Sharing in a Developing Country : Illustrations from Nigeria*, IMF Working Paper No. 03/16, 2003.

Ahonsi, Babatunde A, “Deliberate falsification and census data in Nigeria,” *African affairs*, 1988, *87* (349), 553–562.

Allen, Treb and Costas Arkolakis, “The Welfare Effects of Transportation Infrastructure Improvements,” NBER Working Papers 25487, National Bureau of Economic Research, Inc January 2019.

_ , _ , and Xiangliang Li, “On the Existence and Uniqueness of Trade Equilibria,” Working Paper, *Yale University* July 2015.

Aragon, Fernando M., Francisco Oteiza, and Juan Pablo Rud, “Climate Change and Agriculture: Subsistence Farmers’ Response to Extreme Heat,” *American Economic Journal: Economic Policy*, February 2021, *13* (1), 1–35.

Auffhammer, Maximilian, “Quantifying Economic Damages from Climate Change,” *Journal of Economic Perspectives*, November 2018, *32* (4), 33–52.

Avila, Dias, Antonio Flavio, and Robert E. Evenson, “Total Factor Productivity Growth in Agriculture: The Role of Technological Capital,” in Robert Evenson and Prabhu Pingali, eds., *Handbook of Agricultural Economics*, Vol. 4 of *Handbook of Agricultural Economics*, Elsevier, 00 2010, chapter 72, pp. 3769–3822.

Baez, Javier, German Caruso, Valerie Mueller, and Chiyu Niu, “Heat Exposure and Youth Migration in Central America and the Caribbean,” *American Economic Review*, May 2017, *107* (5), 446–50.

Bairoch, Paul, *Cities and Economic Development: From the Dawn of History to the Present*, Chicago: University of Chicago Press., 1988.

Balboni, Clare, “In Harm’s Way? Infrastructure Investments and the Persistence of Coastal Cities,” *Mimeo, MIT.*, 2021.

Baldomero-Quintana, Luis, “How Infrastructure Shapes Comparative Advantage,” Working Paper, *William & Mary* 2021.

Barreca, Alan, Karen Clay, Olivier Deschênes, Michael Greenstone, and Joseph S. Shapiro, “Convergence in Adaptation to Climate Change: Evidence from High Temperatures and Mortality, 1900-2004,” *American Economic Review*, May 2015, *105* (5), 247–51.

Barrios, Salvador, Luisito Bertinelli, and Eric Strobl, “Climatic change and rural-urban migration: The case of sub-Saharan Africa,” *Journal of Urban Economics*, 2006.

_ , _ , and _ , “Trends in Rainfall and Economic Growth in Africa: A Neglected Cause of the African Growth Tragedy,” *The Review of Economics and Statistics*, May 2010, *92* (2), 350–366.

Bartelme, Dominick, Arnaud Costinot, Dave Donaldson, and Andrés Rodríguez-Clare, “External Economies of Scale and Industrial Policy: A View from Trade,” Working Paper, *UC Berkeley* 2019.

Batello, Caterina, Marzio Marzot, and Adamou Harouna Touré, *The future is an ancient lake: traditional knowledge, biodiversity and genetic resources for food and agriculture in Lake Chad Basin ecosystems*, Food & Agriculture Org., 2004.

Blakeslee, David, Ram Fishman, and Veena Srinivasan, “Way Down in the Hole: Adaptation to Long-Term Water Loss in Rural India,” *American Economic Review*, January 2020, *110* (1), 200–224.

Blankespoor, Brian, Rémi Jedwab, Takaaki Masaki, and Carlos Rodríguez-Castelán, "Spillover Effects of Foreign Conflict: Evidence from Boko Haram," *Working Paper*, 2020.

Boehm, Christoph E., Andrei A. Levchenko, and Nitya Pandalai-Nayar, "The Long and Short (Run) of Trade Elasticities," NBER Working Papers 27064, National Bureau of Economic Research, Inc April 2020.

Bohra-Mishra, Pratikshya, Michael Oppenheimer, and Solomon M Hsiang, "Nonlinear permanent migration response to climatic variations but minimal response to disasters," *Proceedings of the National Academy of Sciences*, 2014, *111* (27), 9780–9785.

Boone, Catherine and Rebecca Simson, "Regional inequalities in African political economy: theory, conceptualization and measurement, and political effects," Economic History Working Papers 100861, London School of Economics and Political Science, Department of Economic History March 2019.

Boustan, Leah Platt, Matthew E. Kahn, and Paul W. Rhode, "Moving to Higher Ground: Migration Response to Natural Disasters in the Early Twentieth Century," *American Economic Review*, May 2012, *102* (3), 238–44.

Burgess, Robin and Dave Donaldson, "Can Openness Mitigate the Effects of Weather Shocks? Evidence from India's Famine Era," *American Economic Review*, May 2010, *100* (2), 449–53.

Burke, Marshall and Kyle Emerick, "Adaptation to Climate Change: Evidence from US Agriculture," *American Economic Journal: Economic Policy*, August 2016, *8* (3), 106–40.

_ , John Dykema, David B. Lobell, Edward Miguel, and Shanker Satyanath, "Incorporating Climate Uncertainty into Estimates of Climate Change Impacts," *The Review of Economics and Statistics*, May 2015, *97* (2), 461–471.

Carleton, Tamma A, Amir Jina, Michael T Delgado, Michael Greenstone, Trevor Houser, Solomon M Hsiang, Andrew Hultgren, Robert E Kopp, Kelly E McCusker, Ishan B Nath et al., "Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits," Technical Report, National Bureau of Economic Research 2020.

Carmouze, J.-P., J.-R. Durand, and C. Lévêque, *Lake Chad. Ecology and Productivity of a Shallow Tropical Ecosystem*, Dr W. Junk Publishers, 1983.

Cattaneo, Cristina and Giovanni Peri, "The migration response to increasing temperatures," *Journal of Development Economics*, 2016, *122*, 127–146.

Cavallo, Eduardo, Sebastian Galiani, Ilan Noy, and Juan Pantano, "Catastrophic Natural Disasters and Economic Growth," *The Review of Economics and Statistics*, December 2013, *95* (5), 1549–1561.

Chen, Chaoran, Diego Restuccia, and Raul Santaeulalia-Llopis, "The Effects of Land Markets on Resource Allocation and Agricultural Productivity," *Review of Economic Dynamics*, 2017.

Chen, Joyce J., Valerie Mueller, Yuanyuan Jia, and Steven Kuo-Hsin Tseng, "Validating Migration Responses to Flooding Using Satellite and Vital Registration Data," *American Economic Review*, May 2017, *107* (5), 441–45.

Collelo, Thomas, *Chad: A Country Study*, Washington: GPO for the Library of Congress, 1988.

Colmer, Jonathan, "Temperature, labor reallocation, and industrial production: Evidence from India," *American Economic Journal: Applied Economics*, 2021, *13* (4), 101–24.

Comission du Bassin du Lac Tchad, "Plan de Développement et d'Adaptation au Changement Climatique du Lac Tchad," 2015.

Conte, Bruno, *Climate change and migration: the case of Africa*, Mimeo, Universita di Bologna., 2021.

_ , Klaus Desmet, David Krisztian Nagy, and Esteban Rossi-Hansberg, "Local Sectoral Specialization in a Warming World," CEPR Discussion Papers 15491, C.E.P.R. Discussion Papers November 2020.

Corno, Lucia, Nicole Hildebrandt, and Alessandra Voena, "Age of Marriage, Weather Shocks, and the Direction of Marriage Payments," *Econometrica*, 2020, *88* (3), 879–915.

Costinot, Arnaud, Dave Donaldson, and Cory Smith, "Evolving Comparative Advantage and the Impact of Climate Change in Agricultural Markets: Evidence from 1.7 Million Fields around the World," *Journal of Political Economy*, 2016, *124* (1), 205–248.

Couttenier, Mathieu and Raphael Soubeyran, "Drought and Civil War In Sub-Saharan Africa," *Economic Journal*, 2014, *124* (575), 201–244.

Couty, Philippe and Pierre Duran, *Le commerce du poisson au Tchad*, Orstom Paris, 1968.

de la Statistique et de la Mécanographie Commissariat Général au Plan, Service, *Annuaire Statistique 1962*.

de Leeuw, P. N. and J. C. Tothill, *The concept of rangeland carrying capacity in sub-Saharan Africa - myth or reality*, Pastoral Development Network No.29, 1990.

de l'Elevage et des Forêts du Cameroun Chambre d'Agriculture, *1962 Cameroun's Economy* 1965.

Dell, Melissa, Benjamin F Jones, and Benjamin A Olken, "Temperature and income: reconciling new cross-sectional and panel estimates," *American Economic Review*, 2009, *99* (2), 198–204.

_ , _ , and _ , "Temperature shocks and economic growth: Evidence from the last half century," *American Economic Journal: Macroeconomics*, 2012, *4* (3), 66–95.

_ , _ , and _ , "What do we learn from the weather? The new climate-economy literature," *Journal of Economic Literature*, 2014, *52* (3), 740–98.

Deschenes, Olivier and Enrico Moretti, "Extreme Weather Events, Mortality, and Migration," *The Review of Economics and Statistics*, November 2009, *91* (4), 659–681.

_ and Michael Greenstone, "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather," *American Economic Review*, March 2007, *97* (1), 354–385.

_ and _ , "Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US," *American Economic Journal: Applied Economics*, October 2011, *3* (4), 152–85.

Deschênes, Olivier, Michael Greenstone, and Jonathan Guryan, "Climate change and birth weight," *American Economic Review*, 2009, *99* (2), 211–17.

Desmet, Klaus and Esteban Rossi-Hansberg, "On the spatial economic impact of global warming," *Journal of Urban Economics*, 2015, *88* (C), 16–37.

_ , Dávid Krisztián Nagy, and Esteban Rossi-Hansberg, "The Geography of Development," *Journal of Political Economy*, 2018, *126* (3), 903–983.

_ , Robert E. Kopp, Scott A. Kulp, Dávid Krisztián Nagy, Michael Oppenheimer, Esteban Rossi-Hansberg, and Benjamin H. Strauss, "Evaluating the Economic Cost of Coastal Flooding," *American Economic Journal: Macroeconomics*, April 2021, *13* (2), 444–486.

Donaldson, Dave, "Railroads of the Raj: Estimating the Impact of Transportation Infrastructure," *American Economic Review*, April 2018, *108* (4-5), 899–934.

Dong, Hongmei, Yougui Song, and Maosheng Zhang, "Hydrological trend of Qinghai Lake over the last 60 years: driven by climate variations or human activities?," *Journal of Water and Climate Change*, 03 2018, *10* (3), 524–534.

Evans, Martin and Yasir Mohieldeen, "Environmental change and livelihood strategies: The case of Lake Chad," *Geography*, 2002, pp. 3–13.

FAO, "Adaptive water management in the Lake Chad Basin. Addressing current challenges and adapting to future needs," in "FAO Water Seminar Proceedings of the World Water Week" 2009.

FAO, *FAOSTAT*, Rome: FAO., 2021.

Felkner, John, Kamilya Tazhibayeva, and Robert Townsend, "Impact of Climate Change on Rice Production in Thailand," *American Economic Review*, May 2009, *99* (2), 205–10.

Florczyk, A.J., C. Corbane, D. Ehrlich, S. Freire, T. Kemper, L. Maffenini, M. Melchiorri, M. Pesaresi, P. Politis, M. Schiavina, F. Sabo, and L. Zanchetta, "GHSL data package 2019," 2019.

Fuglie, Keith O., "Is a slowdown in agricultural productivity growth contributing to the rise in commodity prices?," *Agricultural Economics*, November 2008, *39* (s1), 431–441.

_ and Nicholas E. Rada, *Resources, Policies, and Agricultural Productivity in Sub-Saharan Africa*, Washington, DC: United States Department of Agriculture., 2013.

Galle, Simon, Andrés Rodríguez-Clare, and Moises Yi, "Slicing the Pie: Quantifying the Aggregate and Distributional Effects of Trade," *Forthcoming Review of Economic Studies*, Mimeo, University of California, Berkeley August 2021.

Gollin, Douglas and Christopher Udry, "Heterogeneity, Measurement Error, and Misallocation: Evidence from African Agriculture," *Journal of Political Economy*, 2021, *129* (1), 1–80.

_ , Remi Jedwab, and Dietrich Vollrath, "Urbanization with and without industrialization," *Journal of Economic Growth*, March 2016, *21* (1), 35–70.

Gröger, André and Yanos Zylberberg, "Internal labor migration as a shock coping strategy: Evidence from a typhoon," *American Economic Journal: Applied Economics*, 2016, *8* (2), 123–53.

Guiteras, Raymond, Amir Jina, and A. Mushfiq Mobarak, "Satellites, Self-Reports, and Submersion: Exposure to Floods in Bangladesh," *American Economic Review*, May 2015, *105* (5), 232–36.

Harari, Mariaflavia and Eliana La Ferrara, "Conflict, climate, and cells: a disaggregated analysis," *Review of Economics and Statistics*, 2018, *100* (4), 594–608.

He, Yiyi, Jun Erik Maruyama Rentschler, Paolo Avner, Jianxi Gao, Xiangyu Yue, and John Radke, "Mobility and Resilience : A Global Assessment of Flood Impacts on Road Transportation Networks," Policy Research Working Paper Series 10049, The World Bank May 2022.

Henderson, J. Vernon, Adam Storeygard, and Uwe Deichmann, "Has climate change driven urbanization in Africa?," *Journal of Development Economics*, 2017, *124* (C), 60–82.

Heutel, Garth, Nolan H Miller, and David Molitor, "Adaptation and the mortality effects of temperature across US climate regions," *Review of Economics and Statistics*, 2021, *103* (4), 740–753.

Hornbeck, Richard, "The Enduring Impact of the American Dust Bowl: Short- and Long-Run Adjustments to Environmental Catastrophe," *American Economic Review*, June 2012, *102* (4), 1477–1507.

_ and Pinar Keskin, "The historically evolving impact of the ogallala aquifer: Agricultural adaptation to groundwater and drought," *American Economic Journal: Applied Economics*, 2014, *6* (1), 190–219.

_ and Suresh Naidu, "When the levee breaks: black migration and economic development in the American South," *American Economic Review*, 2014, *104* (3), 963–90.

Hsiang, Solomon and Robert E. Kopp, "An Economist's Guide to Climate Change Science," *Journal of Economic Perspectives*, November 2018, *32* (4), 3–32.

Hsiang, Solomon M and Kyle C Meng, "Tropical economics," *American Economic Review*, 2015, *105* (5), 257–61.

Hsieh, Chang-Tai and Peter J. Klenow, "Misallocation and Manufacturing TFP in China and India," *The Quarterly Journal of Economics*, 2009, *124* (4), 1403–1448.

Hughes, R., J. Hughes, and G. Bernacsek, *A directory of African wetlands*, IUCN, 1992.

IBRD, *Situation Economique de la Republique du Tchad*, Banque Internationale pour la Reconstruction et le Developpement, Departement Afrique., 1968.

Ighobor, Kingsley, "Développer le bassin du lac Tchad," 2019.

IPCC, *IPCC, 2013: Summary for Policymakers*, In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2013.

Jedwab, Remi and Dietrich Vollrath, "Urbanization without growth in historical perspective," *Explorations in Economic History*, 2015, *58* (C), 1–21.

Jedwab, Rémi and Adam Storeygard, "The Average and Heterogeneous Effects of Transportation Investments: Evidence from Sub-Saharan Africa 1960–2010," *Journal of the European Economic Association*, 06 2021. jvab027.

Jessoe, Katrina, Dale T. Manning, and J. Edward Taylor, "Climate Change and Labour Allocation in Rural Mexico: Evidence from Annual Fluctuations in Weather," *Economic Journal*, February 2018, *128* (608), 230–261.

Jones, Benjamin F and Benjamin A Olken, "Climate shocks and exports," *American Economic Review*, 2010, *100* (2), 454–59.

Kahn, Matthew E., "The Death Toll from Natural Disasters: The Role of Income, Geography, and Institutions," *The Review of Economics and Statistics*, 2005, *87* (2), 271–284.

Keys, Benjamin J and Philip Mulder, "Neglected No More: Housing Markets, Mortgage Lending, and Sea Level Rise," Working Paper 27930, National Bureau of Economic Research October

2020.
Kleemans, Marieke and Jeremy Magruder, "Labour Market Responses To Immigration: Evidence From Internal Migration Driven By Weather Shocks," *Economic Journal*, August 2018, *128* (613), 2032–2065.
Knox, Jerry, Tim Hess, Andre Daccache, and Tim Wheeler, "Climate change impacts on crop productivity in Africa and South Asia," *Environmental Research Letters*, sep 2012, *7* (3), 034032.
Kocornik-Mina, Adriana, Thomas KJ McDermott, Guy Michaels, and Ferdinand Rauch, "Flooded cities," *American Economic Journal: Applied Economics*, 2020, *12* (2), 35–66.
Lagakos, David and Michael E. Waugh, "Selection, Agriculture, and Cross-Country Productivity Differences," *American Economic Review*, April 2013, *103* (2), 948–80.
Liu, Maggie Y, Yogita Shamdasani, and Vis Taraz, "Climate change and labor reallocation: Evidence from six decades of the Indian Census," *Available at SSRN 3905985*, 2021.
LoPalo, Melissa, "Temperature, worker productivity, and adaptation: evidence from survey data production," *Available at SSRN 3711044*, 2020.
Luxereau, Anne, Pierre Genthon, and Jean-Marie Ambouta Karimou, "Fluctuations in the size of Lake Chad: consequences on the livelihoods of the riverain peoples in eastern Niger," *Regional Environmental Change*, 2012, *12* (3), 507–521.
Maccini, Sharon and Dean Yang, "Under the weather: Health, schooling, and economic consequences of early-life rainfall," *American Economic Review*, 2009, *99* (3), 1006–26.
Magrin, Géraud, Jacques Lemoalle, and Roland Pourtier, *Atlas du lac Tchad*, Passages, 2015.
Mahajan, Parag and Dean Yang, "Taken by storm: Hurricanes, migrant networks, and us immigration," *American Economic Journal: Applied Economics*, 2020, *12* (2), 250–77.
Marguera, Yves, *Atlas du Cameroun, Planche XVII: Les Villes et leurs Fonctions* 1975.
Martinsson, Jenny, *Changes in the Course of the River Komadugu Yobe during the 20th Century at the Border between Niger and Nigeria*, Master's Thesis TVVR 10/5005, Lund University., 2010.
Mendelsohn, Robert, William D. Nordhaus, and Daigee Shaw, "The Impact of Global Warming on Agriculture: A Ricardian Analysis," *The American Economic Review*, 1994, *84* (4), 753–771.
Michaels, Guy, Yatang Lin, and Thomas K. J. McDermott, "Cities and the sea level," LSE Research Online Documents on Economics 114428, London School of Economics and Political Science, LSE Library April 2021.
Miguel, Edward and Shanker Satyanath, "Re-examining Economic Shocks and Civil Conflict," *American Economic Journal: Applied Economics*, October 2011, *3* (4), 228–32.
— , — , and Ernest Sergenti, "Economic Shocks and Civil Conflict: An Instrumental Variables Approach," *Journal of Political Economy*, 2004, *112* (4), 725–753.
Miller, R.E., R.H. Johnston, J.A.I. Olowu, and J.U. Uzoma, "Ground-water hydrology of the Chad Basin in Bornu and Dikwa Emirates, northeastern Nigeria, with special emphasis on the flow life of the artesian system," 1968.
Miller, Steve, Kenn Chua, Jay Coggins, and Hamid Mohtadi, "Heat Waves, Climate Change, and Economic Output," *Journal of the European Economic Association*, 2021, *19* (5), 2658–2694.
Monte, Ferdinando, Stephen J. Redding, and Esteban Rossi-Hansberg, "Commuting, Migration, and Local Employment Elasticities," *American Economic Review*, December 2018, *108* (12), 3855–3890.
Mortimore, Michael, *Farmers, Famines and Desertification in West Africa*, Cambridge University Press, 1989.
Mpofu, N. and J.E.O. Rege, *The unique Kuri cattle of the Lake Chad Basin. AGTR Case Study.*, Nairobi, Kenya: ILRI., 2002.
NCMRED, *Marine Science Activities of the Nations of Africa*, U.S. Government Printing Office, National Council on Marine Resources and Engineering Development., 1968.
Nelson, Andrew and Uwe Deichmann, "African Population database documentation," Technical Report, United Nations Environment Programme and CIESIN 2004.
New York Times, *As the Great Salt Lake Dries Up, Utah Faces An 'Environmental Nuclear Bomb'*, New York: The New York Times. Published June 7, 2022., 2022.
Nour, A Mahamat, Christine Vallet-Coulomb, J Gonçalves, Florence Sylvestre, and Pierre Deschamps, "Rainfall-discharge relationship and water balance over the past 60 years within

the Chari-Logone sub-basins, Lake Chad basin," *Journal of Hydrology: Regional Studies*, 2021, *35*.

of Commerce, Nigeria. Federal Department, Industries, Nigeria. Federal Ministry of Information, Nigeria. Federal Ministry of Commerce, and Industry, *Handbook of Commerce and Industry in Nigeria* number v. 5, Federal Ministry of Information., 1962.

Okpara, Uche T, Lindsay C Stringer, and Andrew J Dougill, "Lake drying and livelihood dynamics in Lake Chad: Unravelling the mechanisms, contexts and responses," *Ambio*, 2016, *45* (7), 781–795.

Olivry, Jean-Claude, Alfred Chouret, Gabriel Vuillaume, Jacques Lemoalle, and Jean-Pierre Bricquet, *Hydrologie du lac Tchad*, Vol. 12, Orstom, 1996.

Pamo, E. T. and R. D. Pieper, "Analysis of historical range use south of Lake Chad, Cameroon.," 1987.

Pellegrina, Heitor S., "Trade, productivity, and the spatial organization of agriculture: Evidence from Brazil," *Journal of Development Economics*, 2022, *156*, 102816.

Peri, Giovanni and Akira Sasahara, "The impact of global warming on rural-urban migrations: evidence from global big data," *NBER Working Paper*, 2019.

Pham-Duc, Binh, Florence Sylvestre, Fabrice Papa, Frédéric Frappart, Camille Bouchez, and Jean-Francois Crétaux, "The Lake Chad hydrology under current climate change," *Scientific reports*, 2020, *10* (1), 1–10.

Raji, Aminu, "The past history and present trends in the fisheries of Lake Chad," 1993.

Republique du Niger, *Rapport Annuel. Statistiques. 1963-1964*, Ministere de l'Economie Rurale, Direction de l'Elevage et des Industries Animales., 1964.

Restuccia, Diego and Raul Santaeulalia-Llopis, "Land Misallocation and Productivity," Working Papers tecipa-533, University of Toronto, Department of Economics February 2015.

Rosenzweig, Mark R and Christopher Udry, "External Validity in a Stochastic World: Evidence from Low-Income Countries," *Review of Economic Studies*, 2020, *87* (1), 343–381.

Santoze, Adido and Mathiew Gicheha, "The Status of Cattle Genetic Resources in West Africa: A Review," *Advances in Animal and Veterinary Sciences*, 2018, *7* (2), 112–121.

Sayan, R.C., N. Nagabhatla, and M. Ekwuribe, "Soft Power, Discourse Coalitions, and the Proposed Interbasin Water Transfer Between Lake Chad and the Congo River," *Water Alternatives*, 2020, *13* (3), 752–778.

Schlenker, Wolfram, W. Michael Hanemann, and Anthony C. Fisher, "Will U.S. Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach," *The American Economic Review*, 2005, *95* (1), 395–406.

__ , __ , and __ , "The Impact of Global Warming on U.S. Agriculture: An Econometric Analysis of Optimal Growing Conditions," *The Review of Economics and Statistics*, February 2006, *88* (1), 113–125.

Sekhri, Sheetal, "Public Provision and Protection of Natural Resources: Groundwater Irrigation in Rural India," *American Economic Journal: Applied Economics*, October 2011, *3* (4), 29–55.

__ , "Wells, water, and welfare: the impact of access to groundwater on rural poverty and conflict," *American Economic Journal: Applied Economics*, 2014, *6* (3), 76–102.

Seo, S. Niggol and Robert Mendelsohn, "Measuring impacts and adaptations to climate change: a structural Ricardian model of African livestock management1," *Agricultural Economics*, 2008, *38* (2), 151–165.

Shah, Manisha and Bryce Steinberg, "Drought of Opportunities: Contemporaneous and Long-Term Impacts of Rainfall Shocks on Human Capital," *Journal of Political Economy*, 2017, *125* (2), 527 – 561.

Simonovska, Ina and Michael E. Waugh, "The elasticity of trade: Estimates and evidence," *Journal of International Economics*, 2014, *92* (1), 34–50.

Somanathan, Eswaran, Rohini Somanathan, Anant Sudarshan, and Meenu Tewari, "The impact of temperature on productivity and labor supply: Evidence from Indian manufacturing," *Journal of Political Economy*, 2021, *129* (6), 1797–1827.

Sotelo, Sebastian, "Domestic Trade Frictions and Agriculture," *Journal of Political Economy*, 2020, *128* (7), 2690–2738.

Ssentongo, George W and JC Njock, "Marine fishery resources of Cameroon: a review of exploited fish stocks," 1987.

Strobl, Eric, "The economic growth impact of hurricanes: Evidence from US coastal counties," *Review of Economics and Statistics*, 2011, *93* (2), 575–589.

Sultan, B., P. Roudier, P. Quirion, A. Alhassane, B. Muller, M. Dingkuhn, P. Ciais, M. Guimberteau, S. Traore, and C. Baron, "Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa," *Environmental Research Letters*, mar 2013, *8* (1), 014040.

Sédick, Ahmed, "Le Lac Tchad et ses tributaires."

The Atlantic, *Toxic Dust From a Dying California Lake*, The Atlantic. Published November 9, 2015., 2015.

The Conversation, *How the private sector is shaping the future of Lake Chad and the Congo Basin*, The Conversation. Published: June 22, 2021., 2021.

The World Bank, *Advancing Social Protection in a Dynamic Nigeria*, Washington, D.C. : World Bank Group., 2020.

Turner, Matthew A, Jeffrey S Rosenthal, Jian Chen, and Chunyan Hao, "Adaptation to climate change in preindustrial Iceland," *American Economic Review*, 2012, *102* (3), 250–55.

UN, *World Urbanization Prospects: The 2018 Revision*, New York, USA: Department of Economic and Social Affairs Population Dynamics, The United Nations., 2018.

__ , *World Population Prospects: The 2019 Revision*, New York, USA: Department of Economic and Social Affairs Population Dynamics, The United Nations., 2019.

UNEP, *Africa's Lakes: Atlas of Our Changing Environment*, Nairobi, Kenya: Division of Early Warning and Assessment, United Nations Environment Programme (UNEP), 2006.

USGS, *The Fundamentals of the Water Cycle*, Reston, VA: U.S. Geolocical Survey., 2021.

__ , *Specific Heat Capacity and Water*, Resto, VA: U.S. Geolocical Survey., 2021.

Valentinyi, Akos and Berthold Herrendorf, "Measuring Factor Income Shares at the Sector Level," *Review of Economic Dynamics*, October 2008, *11* (4), 820–835.

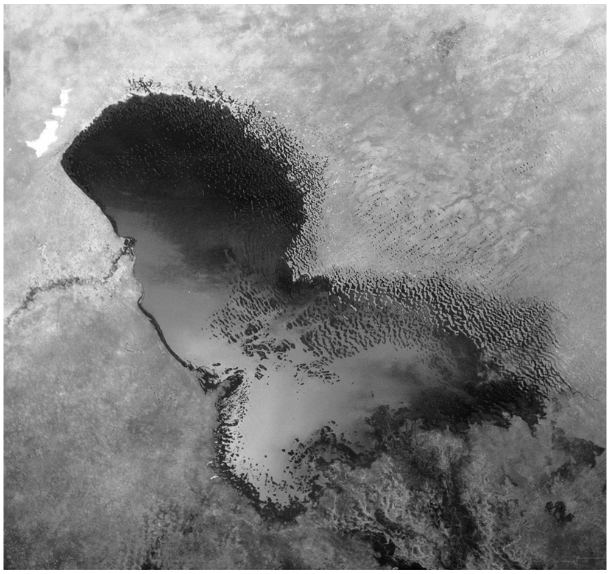
Weil, David N. and Joshua Wilde, "How Relevant Is Malthus for Economic Development Today?," *American Economic Review*, May 2009, *99* (2), 255–60.

Willmott, C. J. and K. Matsuura, *Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series (1900-2017) V 5.01*, University of Delaware Air Temperature & Precipitation, 2001, 2021.

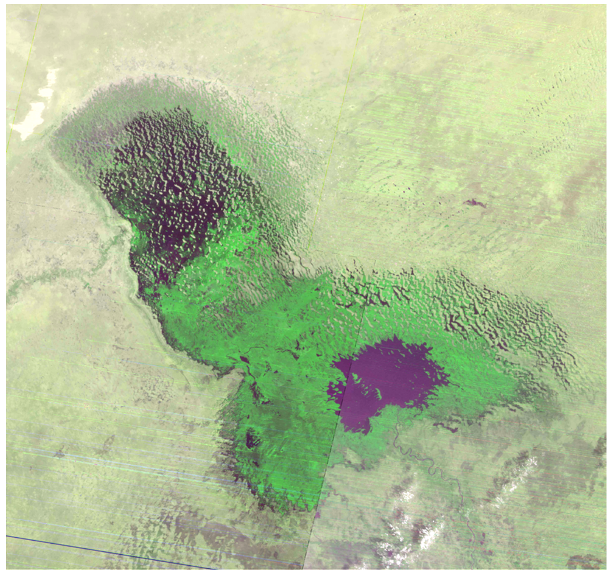
Zainab, Usman, *Economic Diversification in Nigeria: The Politics of Building a Post-Oil Economy*, Bloomsbury Publishing, 2022.

Figure 1: Evolution of Lake Chad, Aerial Photographs, 1960s-2010s

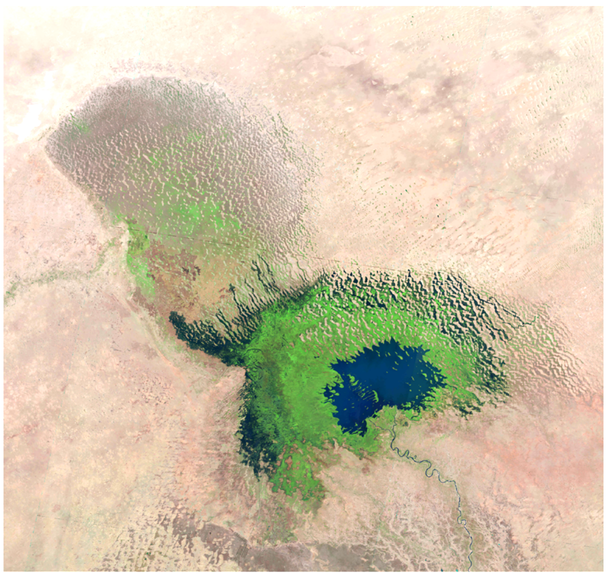
(a) 1963 (Full Lake Phase)



(b) 1976 (Shrinking Lake Chad Phase)



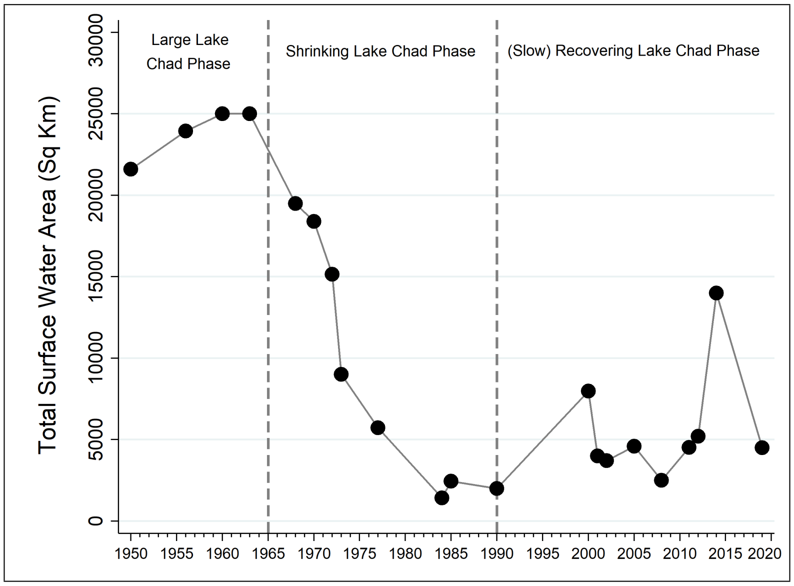
(c) 1987 (Shrinking Lake Chad Phase)



(d) 2013 ((Slow) Recovering Lake Chad Phase)

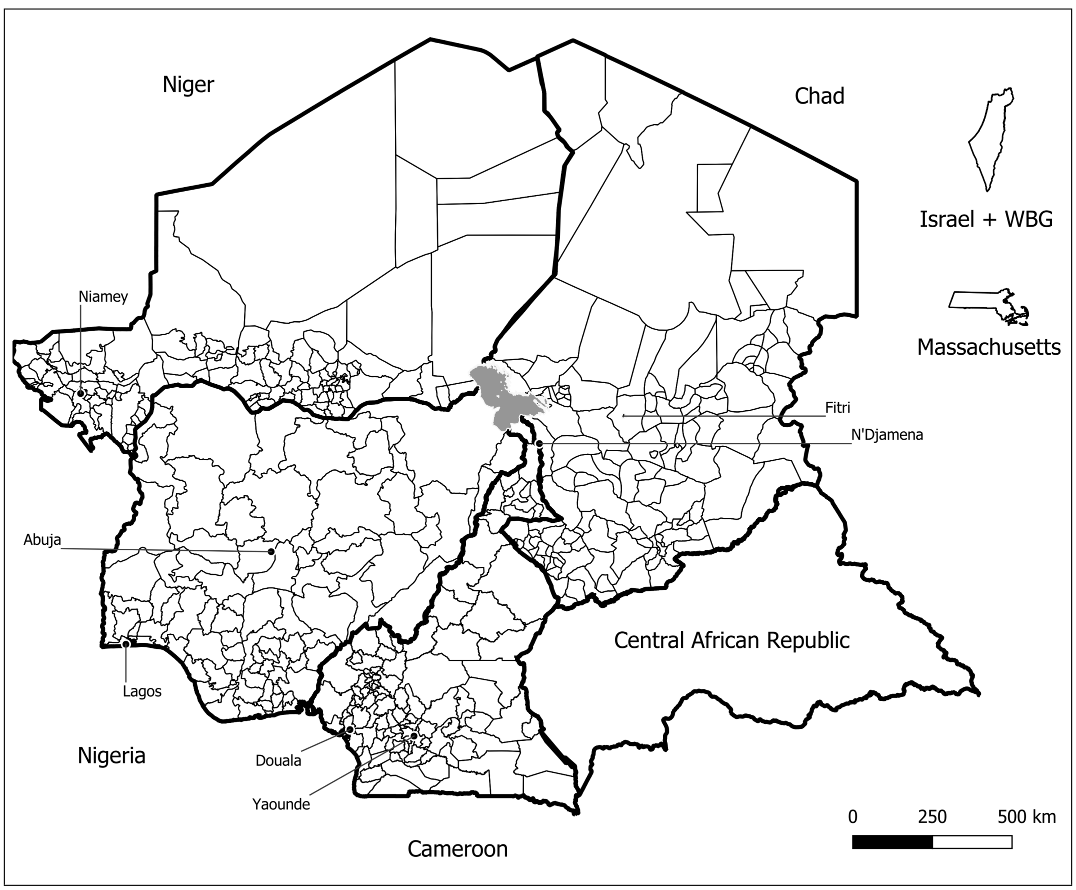
Notes: This figure shows the evolution of Lake Chad from 1963 (large Lake Chad) to 2013 (permanently shrunk Lake Chad). Sources: (i) 1963 - USGS EROS Archive - Declassified Data - Declassified Satellite Imagery – 1; (ii) 1976 – The photo covers the period 02-11-76 / 02-13-76 and comes from the Landsat 1-5 MSS C2 L1 data set; (iii) 1987 - The photo covers the period 01-31-87 / 02-09-87 and comes from the Landsat 4-5 TM C2 L1 data set; and (iv) 2013 - The photo covers the period 05-14-13 / 05-23-13 and comes from the Landsat 8 OLI/TIRS C2 L1 data set. All cited data courtesy of the U.S. Geological Survey.

Figure 2: Evolution of Lake Chad's Total Surface Water Area (Sq Km), 1950-2020



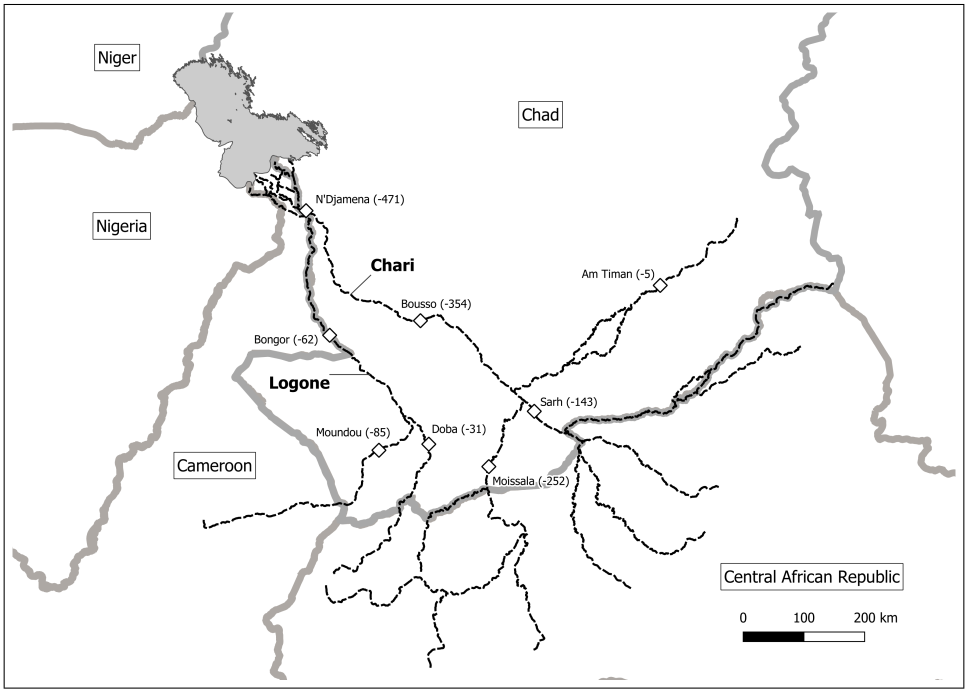
Notes: See Web Data Appendix Section B for details on the sources.

Figure 3: Location of Lake Chad and Subdistrict Boundaries for the Countries of Study



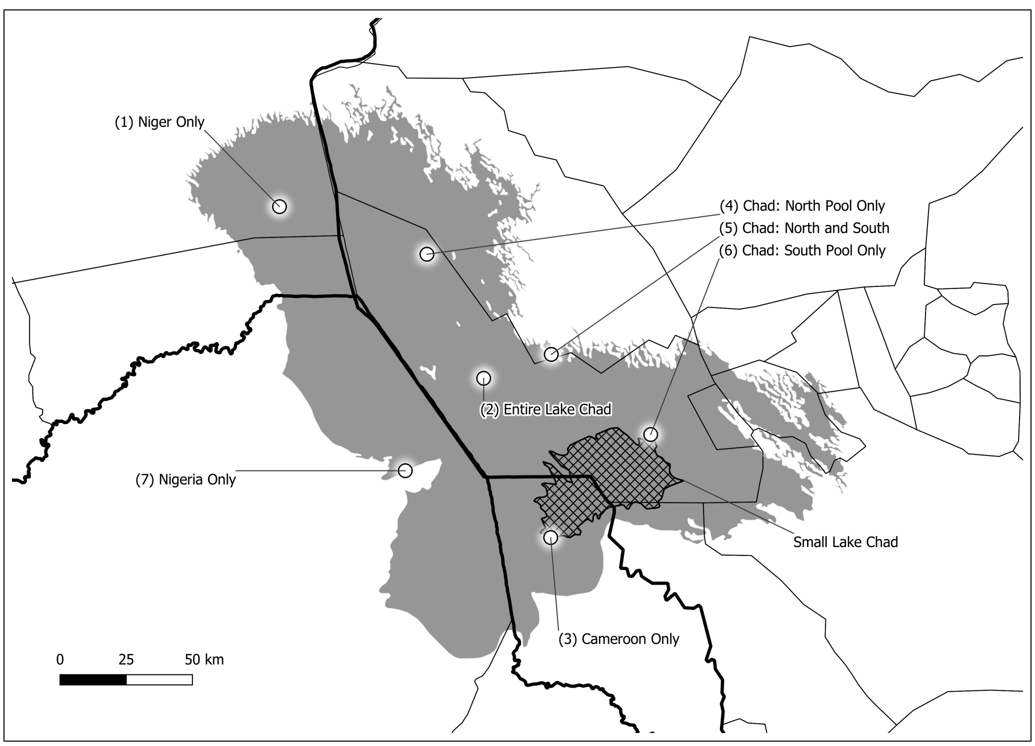
Notes: This figure shows the subdistrict boundaries for the four countries of study for the period c. 1950s-2010s. Cameroon, Chad, Niger and Nigeria are divided into 113, 138, 119 and 83 subdistricts, respectively (453 in total). We show the location of the capital (and most populated city) of Niger (Niamey) and Chad (N'Djamena). For Cameroon and Nigeria, we show their capital city (Yaounde and Abuja) and largest city (Douala and Lagos), respectively. Finally, we indicate the location of Lake Fitri (Chad).

Figure 4: Rivers of the Chari-Logone River System Feeding Lake Chad



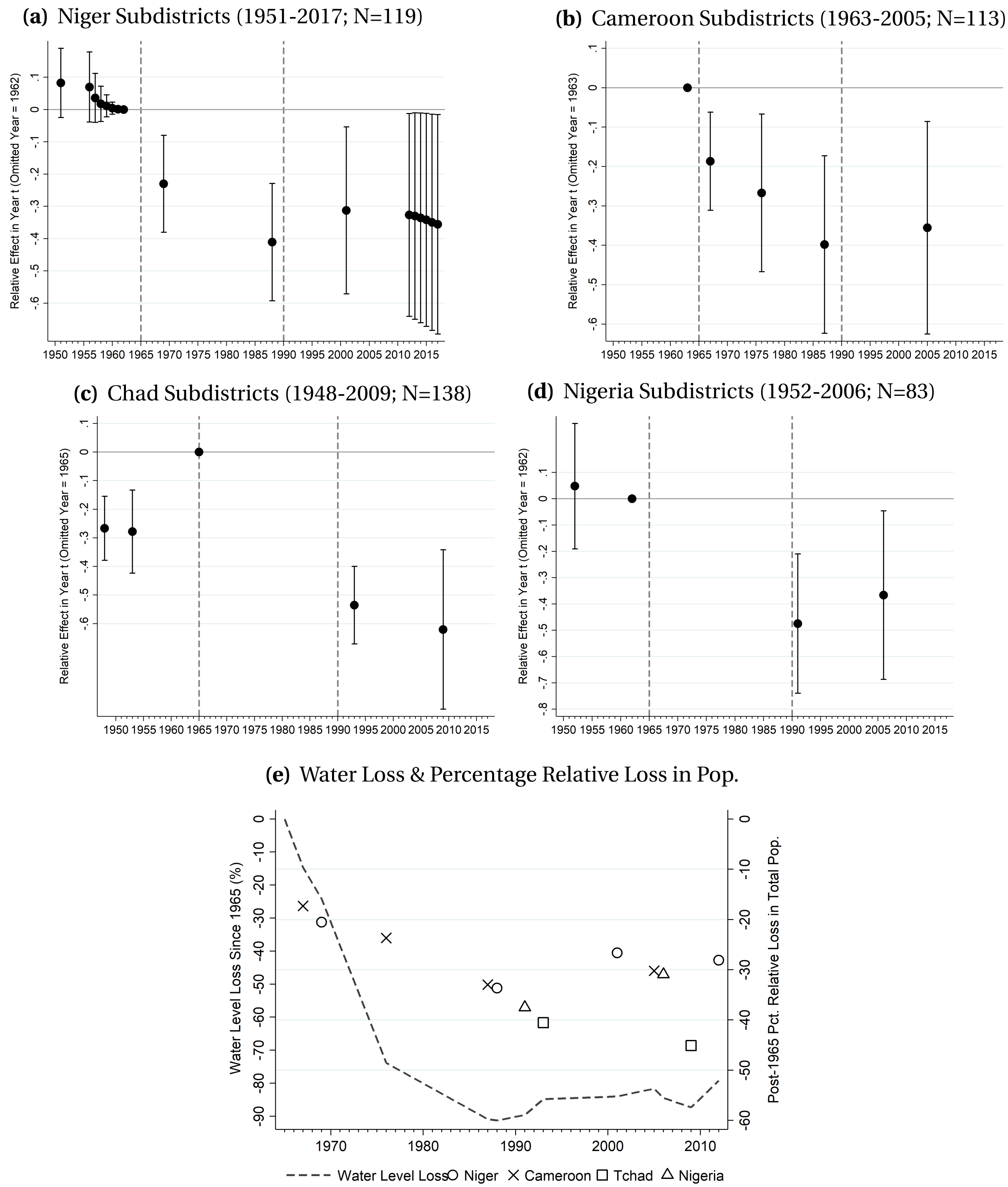
Notes: The Chari and Logone rivers provide almost all of Lake Chad's water. We show in bold the main rivers of the Chari-Logone system. We also show for selected upstream sites of the Chari-Logone river system the absolute reduction in the mean flow rate (m^3/s) between the period 1950-1964 and the period 1965-1980. See Web Data Appx. Sections B and C for details on the sources and analysis, respectively.

Figure 5: Location of the Selected Country-Specific Centroids of Lake Chad



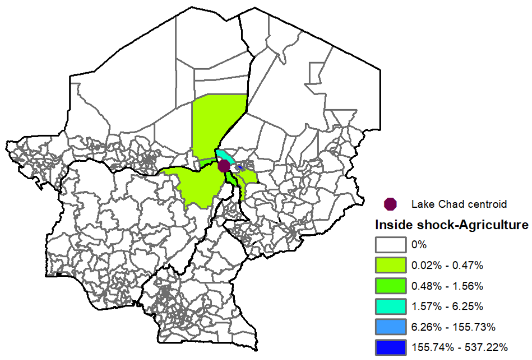
Notes: This figure shows the full (pre-1965) and small (c. 1990 and c. 2020) Lake Chad as well as the centroids of Lake Chad that we consider for each of the four countries of study.

Figure 6: Relative Total Population Effect of Proximity to Lake Chad, 1950s-2010s

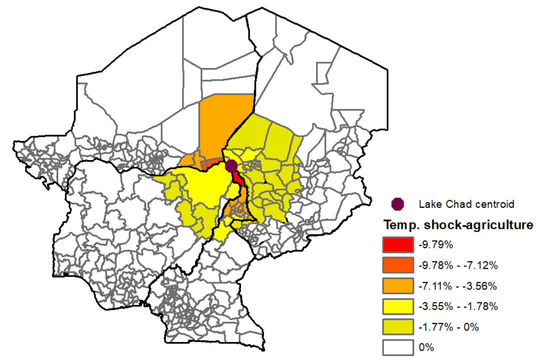


Notes: Subfig. (a)-(d) show for each country the relative total pop. effects of proximity to Lake Chad (relative to the omitted year shown at left). Niger (1951-2017): 119 subdist. x 17 yrs = 2,023. Cameroon (1963-2005): 113 subdist. x 5 yrs = 565. Chad (1948-2009): 138 subdist. x 5 yrs = 690. Nigeria (1952-2006): 83 subdist. x 4 yrs = 332. We include subdist. and year FE, district-specific linear trends, and time-invariant controls interacted with year FE (see text for details). 90% confidence intervals (Conley SEs 100 Km). The dashed vertical lines show the years the lake started to decline (c. 1965) and recover (c. 1990). Subfig. (e) plots the water level loss and the pct. pop. loss in each year (relative to pre-1965).

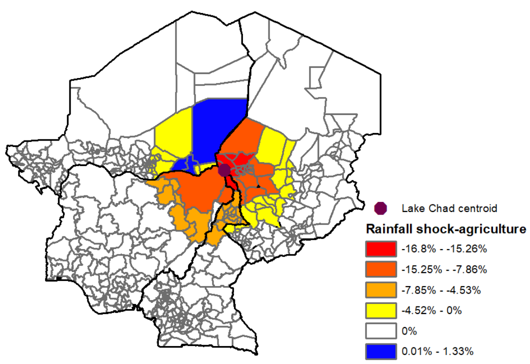
Figure 7: Overall Shock and Sub-Shocks for the Agricultural Sector



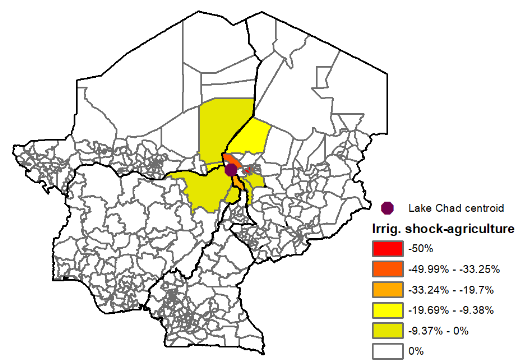
(a) Land Supply Sub-Shock



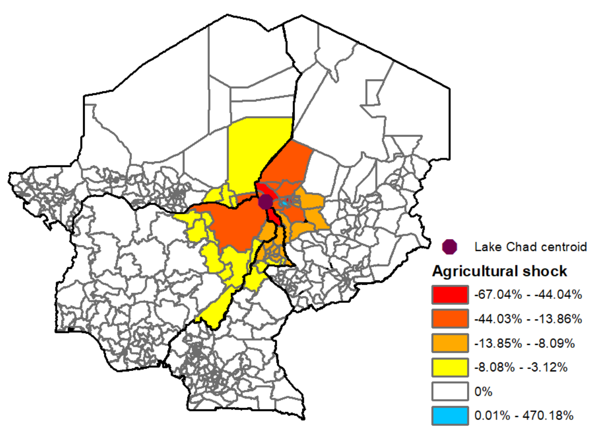
(b) Temperature Sub-Shock



(c) Rainfall Sub-Shock



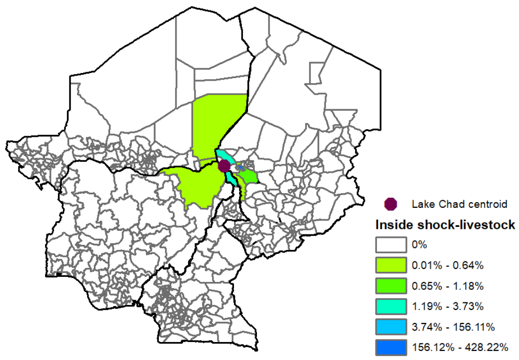
(d) Irrigation Sub-Shock



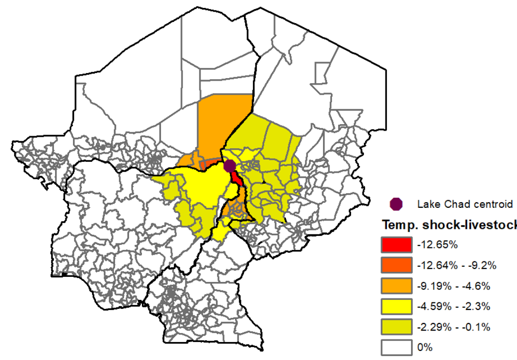
(e) Overall Shock ((a) + (b) + (c) + (d))

Notes: This figure plots the distribution across locations of the productivity shocks in the agricultural sector. Panel (a) shows the positive shock due to land becoming available, panel (b) the negative shock due to increasing temperatures, panel (c) the negative shock due to lower rainfall, panel (d) the negative shock due to lost irrigation, and panel (e) the aggregate shock after summing them up.

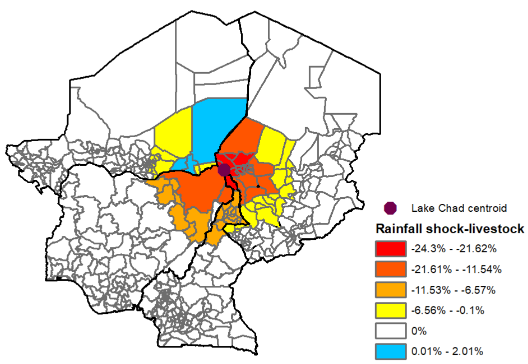
Figure 8: Overall Shock and Sub-Shocks for the Livestock Sector



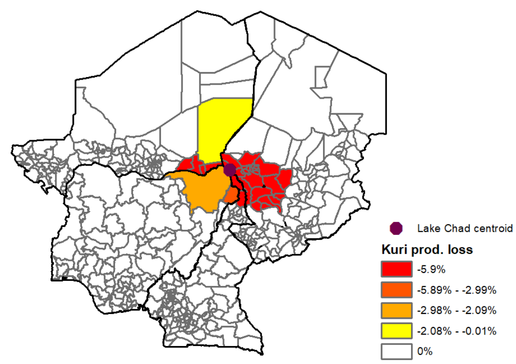
(a) Land Supply Sub-Shock



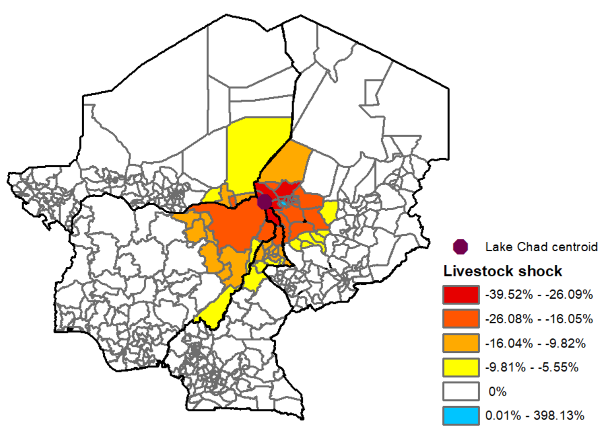
(b) Temperature Sub-Shock



(c) Rainfall Sub-Shock



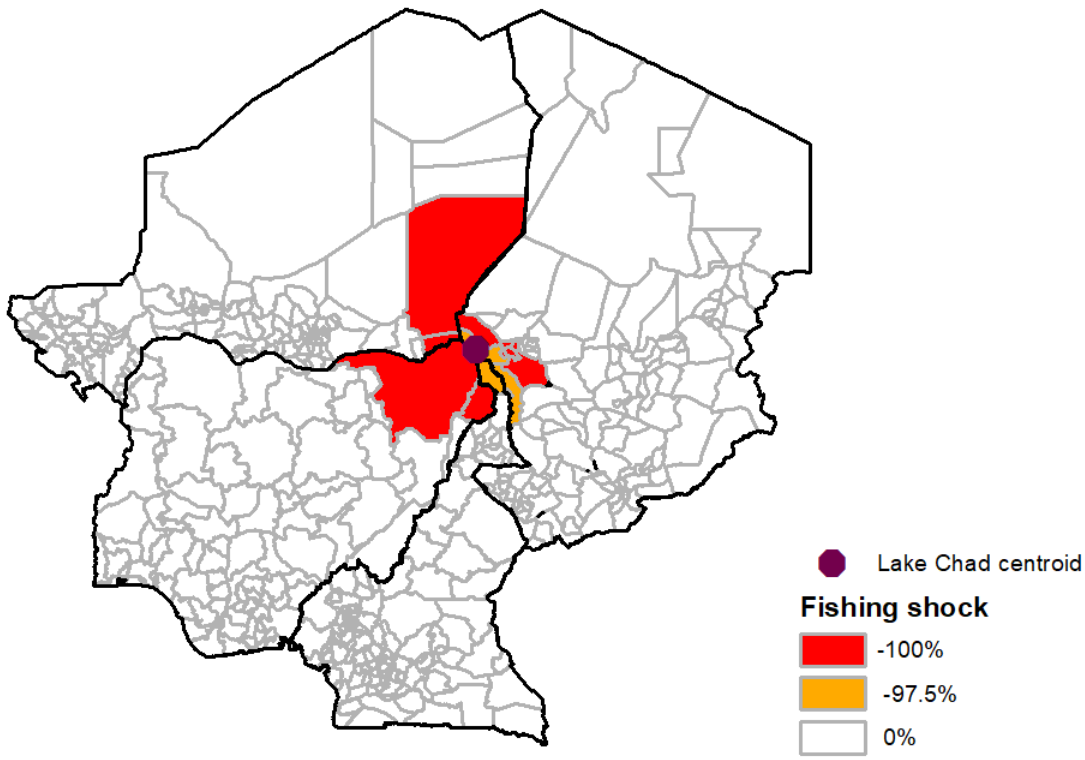
(d) Kuri Extinction Sub-Shock



(e) Overall Shock ((a) + (b) + (c) + (d))

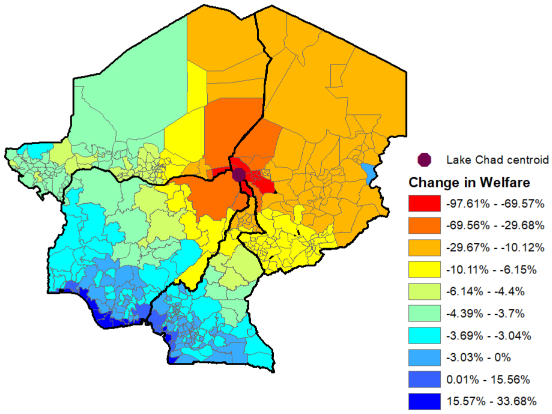
Notes: This figure plots the distribution across locations of the productivity shocks in the livestock sector. Panel (a) shows the positive shock due to land becoming available, panel (b) the negative shock due to increasing temperatures, panel (c) the negative shock due to lower rainfall, panel (d) the negative shock due to the extinction of the Kuri cattle breed, and panel (e) the aggregate shock after summing them up.

Figure 9: Overall Shock for the Fishing Sector

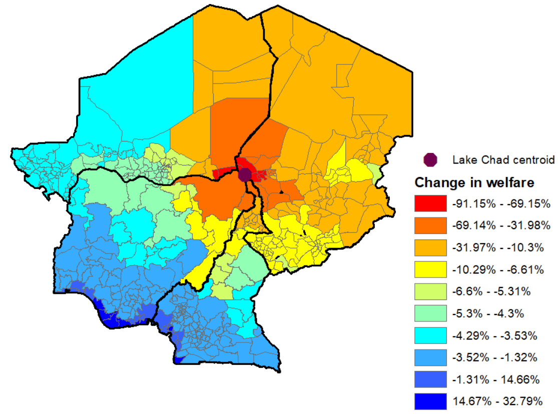


Notes: This figure plots the distribution across locations of the productivity shock in the fishing sector. The shock takes the form of reduced water supply as well as lower water supply quality.

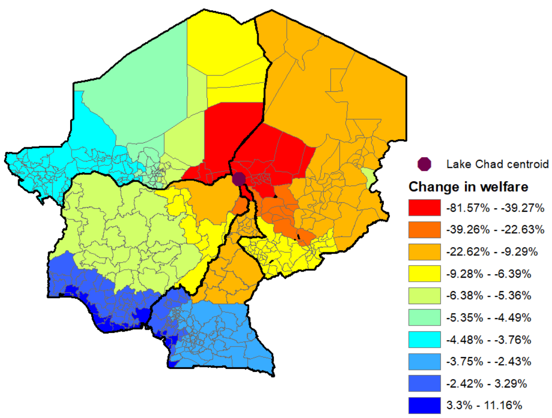
Figure 10: Spatial Distribution: % Δ Welfare



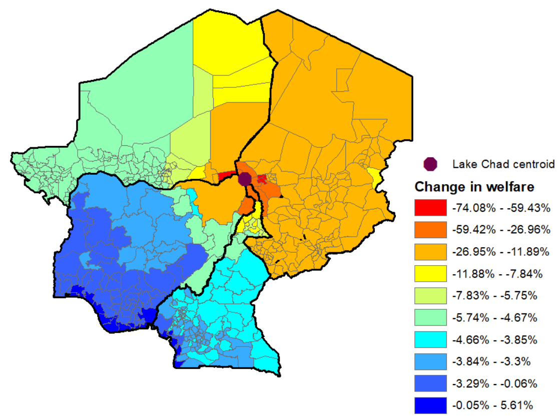
(a) No-migration



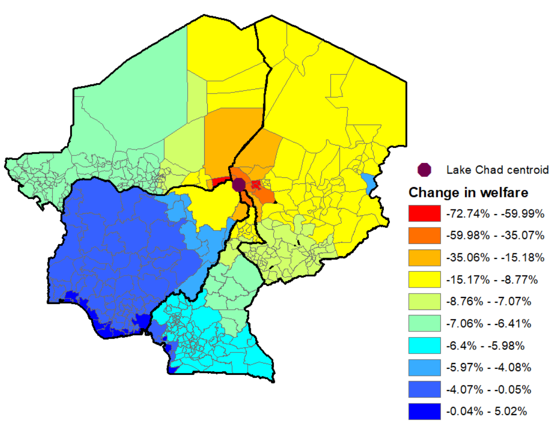
(b) Migration within ethnic groups



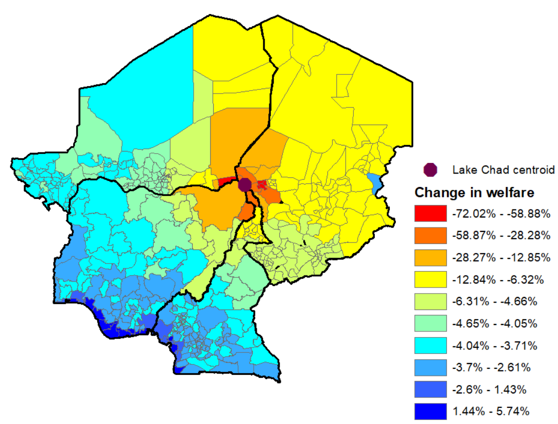
(c) Migration within country-regions



(d) Migration within countries



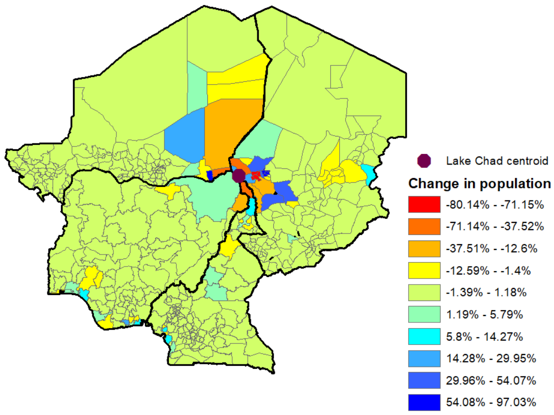
(e) Migration Cameroon Chad Niger



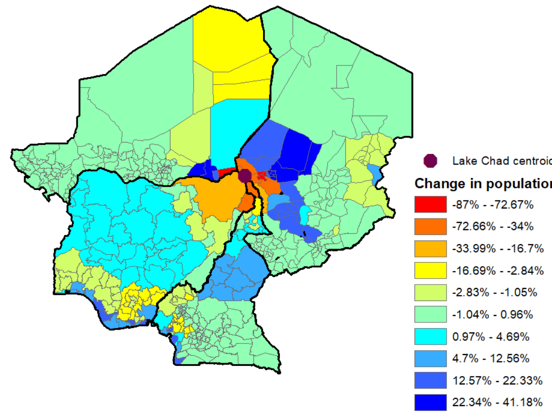
(f) Free migration

Notes: This figure plots the change in welfare across subdistricts after the shock. Panel (a) considers the no-migration scenario (infinite migration costs), (b) a scenario in which there is only migration within subdistricts that have the same ethnic group, (c) a case in which there is only migration within country-regions, (d) a case in which there is only free migration within each country, (e) a case in which there is only free migration between Chad, Cameroon and Niger, and (f) the free migration scenario.

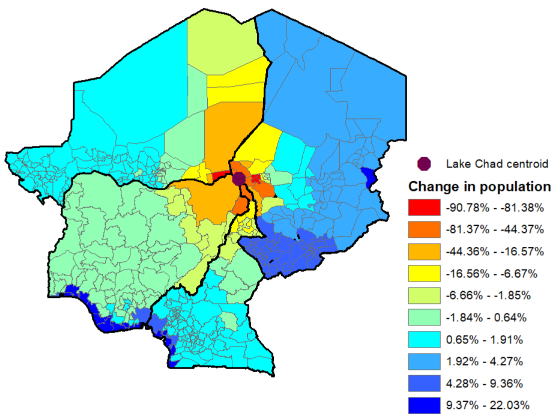
Figure 11: Spatial Distribution: % Δ Total Population



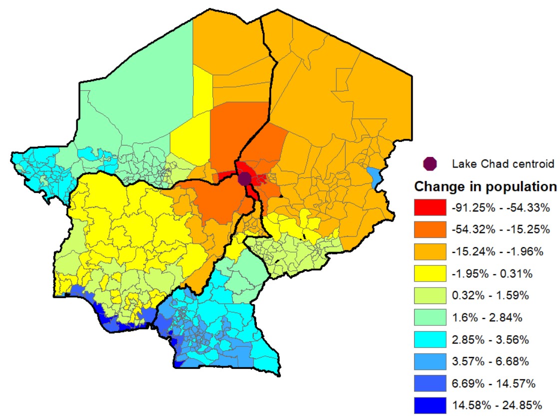
(b) Migration within ethnic groups



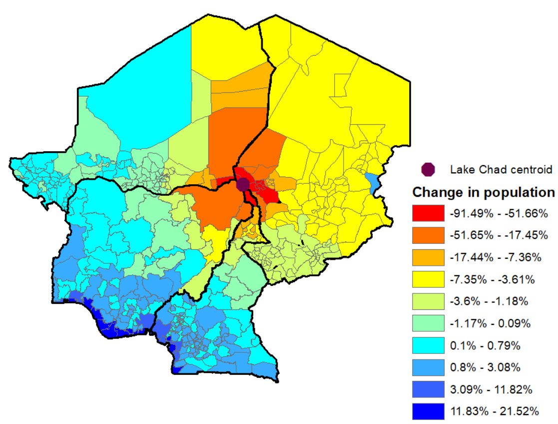
(c) Migration within country regions



(d) Migration within countries



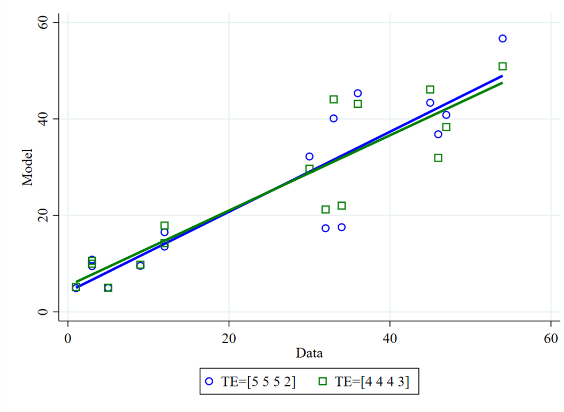
(e) Migration Cameroon Chad Niger



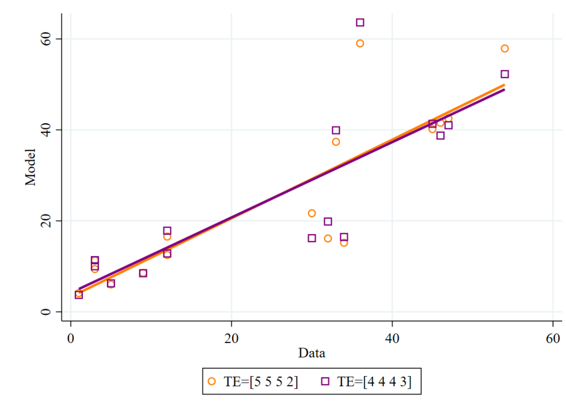
(f) Free migration

Notes: This figure plots the change in population across subdistricts after the shock. We do not report Panel (a), the no-migration scenario. Panel (b) considers a scenario in which there is only migration within subdistricts that have the same ethnic group, (c) a case in which there is only migration within country-regions, (d) a case in which there is only free migration within each country, (e) a case in which there is only free migration between Chad, Cameroon and Niger, and (f) the free migration scenario.

Figure 12: Model fit-GDP shares baseline



(a) Labor share in urban = 0.7



(b) Labor share in urban = 0.5

Notes: This figure plots the fit between the model and the data using aggregate GDP shares in 1965. Panel (a) shows the results using a labor share in the urban sector of 0.7 (as in our baseline calibration), and panel (b) using a labor share of 0.5. TE is the trade elasticity. We consider two combinations: 5 - 1 in the three primary sectors and 2 - 1 in the urban sector as well as 4 - 1 in the three primary sectors and 3 - 1 in the urban sector. The regression coefficient is around 0.8 for all regressions and the R-squared is 0.8.

Table 1: **Reduced-Form Effect, Total Population, Niger 1950s-2010s**

Dependent Variable:	Log Subdistrict Population in Year t				
Test:	Baseline	Full Lake Centroid	Other Inflow River Control	Climate Controls	Conley SE 250 Km
(Relative to the Omitted Year = 1962)	(1)	(2)	(3)	(4)	(5)
Proximity to Lake (log)*c.1990 ($t = 1988$)	-0.41***	-0.59***	-0.48**	-0.42***	-0.41***
	[0.11]	[0.17]	[0.21]	[0.12]	[0.08]
Proximity to Lake (log)*c.2010 ($t = 2001$)	-0.31**	-0.48**	-0.48	-0.32**	-0.31**
	[0.16]	[0.24]	[0.31]	[0.16]	[0.16]
Proximity to Lake (log)*c.2010 ($t = 2012$)	-0.33*	-0.52*	-0.38	-0.32*	-0.33**
	[0.19]	[0.29]	[0.37]	[0.19]	[0.16]
Subdistrict (119) FE, Year (17) FE	Y	Y	Y	Y	Y
District (31) Trends, Controls	Y	Y	Y	Y	Y

Notes: 119 subdist. x 17 years (1951-2017) = 2,023 obs. For each subdistrict centroid, *Proximity to Lake (log)* is the negative of the log Euclidean distance to the selected lake centroid. We only report the coefficients for the closest years to the year 1990 and 2010. Except in (2), the lake centroid is the centroid of Lake Chad within Niger's territory (Fig. 5). (2): Centroid of the full lake. (3): We add a dummy if the subdistrict contains the Komadugu-Yobe river, which we interact with year FE. (4): We control for the log of mean annual rainfall and the log of mean temperature in the period [t-2; t]. In addition to the district-specific linear trends, we include the following time-invariant controls interacted with year FE: log Euclidean distance to the largest/capital city (Niamey) and its square, and latitude. Conley SEs 100 Km ((5): 250 km).

Table 2: **Reduced-Form Effect, Four Countries, Distance Bins**

Dependent Variable:	Log Subdistrict Population in Year t				
Country:	Niger		Cameroon	Chad	Nigeria
Omitted Year = Early 1960s	(1)		(2)	(3)	(4)
Year t used:	1988		1987	1991	1993
Lake 0-150 Km*c.1990 (t)	-0.64***		-1.22***	-0.85***	-0.82*
	[0.08]		[0.23]	[0.28]	[0.44]
Lake 150-300 Km*c.1990 (t)	-0.60***		-0.85***	-0.76***	-0.19
	[0.08]		[0.13]	[0.22]	[0.27]
Lake 300-450 Km*c.1990 (t)	-0.07		-0.88***	-0.36***	0.00
	[0.05]		[0.13]	[0.12]	[0.16]
Year t used:	2001	2012	2005	2006	2009
Lake 0-150 Km*c.2010 (t)	-0.49***	-0.63***	-1.41***	-0.91***	-0.99***
	[0.13]	[0.15]	[0.27]	[0.40]	[0.29]
Lake 150-300 Km*c.2010 (t)	-0.51***	-0.42***	-0.98***	-0.73**	-0.96***
	[0.12]	[0.09]	[0.09]	[0.34]	[0.24]
Lake 300-450 Km*c.2010 (t)	-0.16**	-0.05	-1.08***	-0.37**	0.02
	[0.08]	[0.08]	[0.06]	[0.16]	[0.02]
Subdistrict FE, Year FE	Y		Y	Y	Y
District Trends, Controls	Y		Y	Y	Y

Notes: Obs.: Niger (1951-2017): 119 subdist. x 17 yrs = 2,023. Cameroon (1963-2005): 113 subdist. x 5 yrs = 565. Nigeria (1952-2006): 83 subdist. x 4 yrs = 332. Chad (1948-2009): 138 subdist. x 5 yrs = 690. We omit 1962, 1963, 1963 and 1965, respectively. See text for details on the controls. Conley SEs (100 Km).

Table 3: **Reduced-Form Effect, Rural Population, Four Countries, Distance Bins**

Dependent Variable:	Log Subdistrict Population in t			Log Subdistrict Population in t		
Omitted Year = Early 60s	Total	Rural (5K)	Rural (20K)	Total	Rural (5K)	Rural (20K)
	Niger (t = 2001)			Niger (t = 2012)		
0-150 Km*ca.2010 (t)	-0.26**	-0.45***	-0.51***	-0.34**	-0.69***	-0.76***
	[0.12]	[0.11]	[0.10]	[0.14]	[0.12]	[0.13]
150-300 Km*ca.2010 (t)	-0.26**	-0.48***	-0.35***	-0.10	-0.46***	-0.43***
	[0.11]	[0.12]	[0.09]	[0.15]	[0.14]	[0.14]
300-450 Km*ca.2010 (t)	-0.13	-0.17*	-0.23***	-0.02	-0.18*	-0.28***
	[0.16]	[0.10]	[0.09]	[0.18]	[0.10]	[0.08]
	Cameroon (t = 2005)			Chad (t = 2009)		
0-150 Km*ca.2010 (t)	-1.41***	-0.90***	-1.90***	-1.03***	-0.50*	-0.48
	[0.27]	[0.20]	[0.40]	(0.29)	(0.27)	(0.32)
150-300 Km*ca.2010 (t)	-0.98***	-1.11***	-2.08***	-0.96***	-0.53**	-0.48*
	[0.09]	[0.11]	[0.25]	(0.25)	(0.22)	(0.27)
300-450 Km*ca.2010 (t)	-1.08***	-1.10***	-2.29***	0.01	-0.51***	-0.50***
	[0.06]	[0.11]	[0.23]	(0.03)	(0.11)	(0.15)
Subdistrict FE, Year FE	Y	Y	Y	Y	Y	Y
District Trends, Controls	Y	Y	Y	Y	Y	Y

Notes: Obs.: Niger (1951-2012): 119 subdist. x 12 yrs = 1,428. Cameroon (1963-2005): 113 subdist. x 5 yrs = 565. Chad (1948-2009): 138 subdist. x 5 yrs = 690. We omit 1962, 1963 and 1965, respectively. Rural pop. 5K (20K) = total pop. - total pop. of 5K+ (20K+) cities. See text for details on the controls. Conley SEs (100 Km).

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

Benchmark = 1950-1964	(1) Niger	(2) Cameroon	(3) Nigeria	(4) Chad
Dependent Variable:	Log Mean Annual Rainfall (mm) in the Subdistrict in Period t			
0-150 Km*(1980-1994)	-0.079***	-0.261***	-0.126***	-0.253***
	[0.017]	[0.034]	[0.021]	[0.039]
150-300 Km*(1980-1994)	-0.043	-0.047*	-0.175***	-0.197**
	[0.028]	[0.028]	[0.024]	[0.036]
300-450 Km*(1980-1994)	-0.055***	-0.047**	-0.095*	-0.035*
	[0.017]	[0.023]	[0.050]	[0.017]
Dependent Variable:	Log Mean Monthly Temperature (Celsius) in the Subdistrict in Period t			
0-150 Km*(1980-1994)	0.013***	0.037***	0.006**	0.008***
	[0.002]	[0.006]	[0.003]	[0.003]
150-300 Km*(1980-1994)	0.006***	0.015**	0.013***	0.003
	[0.002]	[0.006]	[0.003]	[0.002]
300-450 Km*(1980-1994)	-0.008***	0.003	0.004	0.002
	[0.002]	[0.006]	[0.002]	[0.002]
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: 113 Subdist. x 13 Periods = 1,469. Nigeria: 83 Subdist. x 13 Periods = 1,079. Chad: 138 Subdist. x 13 Periods = 1,794. We report the difference between the average effect for the periods 1980-84, 1985-89 and 1990-94 and the average effect for the periods 1950-54, 1955-59 and 1960-64 (omitted = 2010-14). Conley SEs 100 Km.

Table 5: Aggregate Economic Losses Depending on the Migration Scenario

	(1) Four Countries	(2) Chad	(3) Niger	(4) Nigeria	(5) Cameroon
Migration scenario:	*Panel A: Congestion Force λ = -0.32*				
1. Free migration	4.1%	7.8%	4.7%	3.8%	4.2%
2. Migration Cameroon-Chad-Niger	7.2%	10.2%	7.2%	3.2%	6.7%
3. Migration within countries	8.7%	14.6%	6.0%	3.2%	4.4%
4. Migration within country-regions	7.2%	12.4%	8.6%	5.8%	7.5%
5. Migration within ethnic groups	7.0%	17.0%	6.8%	8.3%	3.6%
6. No migration	8.4%	14.7%	8.9%	7.5%	5.6%
Mean of 1.-6.	7.1%	12.8%	7.0%	5.3%	5.3%
Migration scenario:	*Panel B: No Congestion Force (λ = 0)*				
1. Free migration	3.9%	8.4%	4.7%	3.6%	4.1%
2. Migration Cameroon-Chad-Niger	5.1%	10.3%	6.8%	3.1%	6.2%
3. Migration within countries	4.5%	14.0%	5.7%	3.1%	4.2%
4. Migration within country-regions	6.5%	11.2%	6.8%	6.0%	7.2%
5. Migration within ethnic groups	6.0%	14.5%	5.4%	10.5%	3.4%
6. No migration	9.2%	14.4%	6.8%	9.5%	5.9%
Mean of 1.-6.	5.9%	12.1%	6.0%	6.0%	5.2%

Notes: This table reports aggregate economic losses when we simulate the shock of the Lake Chad's shrinkage. Panel A shows the results when we simulate the model with a congestion force based on Desmet et al. (2018), and panel B for the case when there are no congestion forces. Column (5) shows the aggregate effects for the four countries. Columns (1) through (4) show the effects for each country.

Table 6: Population Effects of Proximity to the Lake - Simulated Data

VARIABLES	(1) Δ ln L	(2) Δ ln L	(3) Δ ln L	(4) Δ ln L	(5) Δ ln L
Country	Aggregate	Cameroon	Chad	Niger	Nigeria
Country Fixed Effects	Y	N	N	N	N
	Panel A: Free migration				
- ln dist. lake	-0.246***	-0.135***	-0.430***	-0.162***	-0.137***
	(0.019)	(0.011)	(0.048)	(0.023)	(0.016)
Observations	453	113	138	119	83
R-squared	0.325	0.566	0.368	0.296	0.475
	Panel B: Migration within Chad-Cameroon-Niger				
- ln dist. lake	-0.246***	-0.135***	-0.430***	-0.163***	-0.137***
	(0.019)	(0.011)	(0.048)	(0.023)	(0.016)
Observations	453	113	138	119	83
R-squared	0.319	0.565	0.368	0.297	0.473
	Panel C: Migration within countries				
- ln dist. lake	-0.246***	-0.134***	-0.430***	-0.162***	-0.137***
	(0.019)	(0.011)	(0.048)	(0.023)	(0.016)
Observations	453	113	138	119	83
R-squared	0.292	0.564	0.368	0.296	0.473
	Panel D: Migration within country-regions				
- ln dist. lake	-0.133***	-0.081***	-0.234***	-0.066***	-0.098***
	(0.018)	(0.013)	(0.049)	(0.021)	(0.017)
Observations	453	113	138	119	83
R-squared	0.115	0.251	0.144	0.080	0.282
	Panel E: Migration within ethnic groups				
- ln dist. lake	-0.068***	-0.047***	-0.126***	-0.025	-0.039***
	(0.014)	(0.008)	(0.040)	(0.017)	(0.011)
Observations	453	113	138	119	83
R-squared	0.050	0.263	0.067	0.018	0.130

Notes: This table reports the results from a regression in which we relate the long-run log change in population to the log of the Euclidean distance from each subdistrict's centroid to its country-specific lake centroid using simulated data from the model to replicate our reduced-form estimates. Panel (a) reports the results for the free migration scenario, panel (b) for the within Cameroon-Chad-Niger scenario, panel (c) for the within-countries scenario, panel (d) for the within country-regions scenario, and panel (e) for the within-ethnic groups scenario. Column (1) shows the overall point estimate with country fixed-effects. Columns (2) to (5) show the point estimate specific to each country. ***p<0.01, **p<0.05, *p<0.1.

Table 7: Migration and Non-Migration Policies - Aggregate Effects

Policy / Migration Scenario:	No migration	Cntry-regions	Country	Cmrn-Chad-Niger	Free migration
1. Baseline	-8.41	-7.17	-8.72	-7.25	-4.08
2. Lower migration costs		1.24	-0.31	1.16	4.33
3. Land development in lake 15% (best cntry)	0.00	0.00	0.00	0.00	0.00
4. Land development in lake 25%	-0.01	0.00	0.01	0.00	0.00
5. Land development in lake 50%	-0.02	0.00	0.02	0.01	0.00
6. Land development in lake 100%	-0.03	0.01	0.05	0.03	0.01
7. Roads - same budget - "around lake"	0.03	0.31	0.72	0.40	0.13
8. Roads - specific budget - "around lake"	0.00	0.28	0.61	0.35	0.12
9. Roads - same budget - "lake-to-cities"	0.21	0.29	0.61	0.28	0.12
10. Roads - specific budget - "lake-to-cities"	0.30	0.32	0.61	0.35	0.14
11. Roads - same budget - "cities-to-lake"	0.81	0.56	0.96	0.60	0.21
12. Roads - specific budget - "cities-to-lake"	0.63	0.46	0.70	0.44	0.19
13. Tariffs 10% (20% before) - All Sectors	0.80	0.46	1.04	0.64	0.18
14. Tariffs 10% (20% before) - Primary Sectors	0.78	0.48	0.84	0.52	0.19
15. Tariffs 10% (20% before) - Urban Sector	0.81	0.45	1.01	0.63	0.17
16. Congestion externality -0.2 (-0.32 before)	-0.09	0.77	2.22	0.86	0.17
17. Agglomeration externality 0.2 (0.1 before)	0.00	0.09	0.12	0.02	-0.01

Notes: This table reports the results for the aggregate effects of the different policies that we simulate to mitigate the negative effects of the shrinkage of Lake Chad. Each cell corresponds to how much the policy would contribute to reducing the aggregate loss across the four countries. To obtain this number, we compare the effect of the policy before and after the shock. We simulate 15 different policies divided into four different categories: land development, road construction, trade liberalization, and absorption capacity of locations and cities.

Table 8: Migration and Non-Migration Policies - Aggregate Effects - Lake Chad Region (Subdistricts $\leq$ 450 Km)

Policy / Migration Scenario:	**No migration**	**Cntry-regions**	**Country**	**Cmrn-Chad-Niger**	**Free migration**
1. Baseline	-31.05	-20.34	-14.77	-11.61	-9.31
2. Lower migration costs		10.72	16.28	19.44	21.74
3. Land development in lake 15% (best cntry)	0.00	0.01	0.00	0.00	0.00
4. Land development in lake 25%	0.01	0.02	0.01	0.01	0.00
5. Land development in lake 50%	0.03	0.05	0.05	0.03	0.02
6. Land development in lake 100%	0.09	0.11	0.12	0.07	0.04
7. Roads - same budget - "around lake"	4.19	-0.38	1.35	0.62	0.27
8. Roads - specific budget - "around lake"	4.22	-0.53	1.20	0.57	0.26
9. Roads - same budget - "lake-to-cities"	4.04	-0.15	1.19	0.51	0.26
10. Roads - specific budget - "lake-to-cities"	4.20	0.14	1.19	0.59	0.28
11. Roads - same budget - "cities-to-lake"	4.73	1.51	1.71	0.93	0.46
12. Roads - specific budget - "cities-to-lake"	4.48	0.98	1.32	0.72	0.39
13. Tariffs 10% (20% before) - All Sectors	4.42	1.08	1.72	0.87	0.34
14. Tariffs 10% (20% before) - Primary Sectors	4.33	1.20	1.49	0.78	0.35
15. Tariffs 10% (20% before) - Urban Sector	4.51	0.92	1.72	0.87	0.33
16. Congestion externality -0.2 (-0.32 before)	2.94	7.11	1.83	0.70	-0.44
17. Agglomeration externality 0.2 (0.1 before)	0.15	0.34	0.05	0.02	0.03

Notes: This table reports for the Lake Chad region the results for the aggregate effects of the different policies that we simulate to mitigate the negative effects of the shrinkage of Lake Chad. Each cell corresponds to how much the policy would contribute to reducing the aggregate loss across the four countries. To obtain this number, we compare the effect of the policy before and after the shock. We simulate 15 different policies divided into four different categories: land development, road construction, trade liberalization, and absorption capacity of locations and cities.

WEB APPENDIX NOT FOR PUBLICATION

A Shrinkage of Lakes and Drying of Rivers Across the World

In addition to the Aral Sea, Lake Urmia, the Great Salt Lake and the Salton Sea, examples of drying lakes include: (i) The Dead Sea, that is drying due to climate change;[62] (ii) Qinghai Lake, China's largest lake, during most of the 20th century (Dong et al., 2018). The lake "is not only a natural barrier preventing the spread of desertification from the west to the east, but also has a significant influence on climate in the Yellow River catchment;"[63] (iii) Poyang Lake in China, due to repeated droughts as well as the Three Gorges Dam upriver on the Yangtze River;[64] (iv) Lake Poopo in Bolivia, due to climate change;[65] and (v) Hamun Lake in Afghanistan and Iran, due to extreme droughts;[66] Other examples include Lop Nur in Mongolia, Lake Chapala in Mexico, the Dead Sea, Lake Ebinur in China and Lake Faguibine in Mali, almost always due climate change.[67]

In the United States, more examples of drying lakes include: (i) Pyramid Lake in Nevada; (ii) Owens Lake, another Californian lake that is now a major source of dust pollution; (iii) Walker Lake in Nevada; and (iv) Mono Lake in California.[68] Very recently, the shrinkage of Lake Mead in Nevada has alarmed the media.[69] Similar concerns have been raised for Lake Powell in Arizona and Utah.[70] Lastly, California's reservoirs, lakes and rivers keep drying year after year.[71] One example is Lake Tahoe.[72]

Other examples of drying lakes and rivers very recently highlighted in the media include: (i) The Parana River in Brazil, Paraguay and Argentina;[73]; (ii) Lake Maracaibo, one of South America's largest lakes;[74]; (iii) Lake Tuz and other lakes in Turkey.[75]; (iv) Sun

[62]The L.A. Times writes: "The Dead Sea is dying. Drinking water is scarce. Jordan faces a climate crisis [...] the Dead Sea's level has fallen almost 100 feet." See www.latimes.com/world-nation/story/2021-04-15/the-dead-sea-is-dying-drinking-water-is-scarce-jordan-faces-a-climate-crisis.

[63]It has been recovering due to "increased precipitation and snow melt resulting from climate change."

[64]See https://www.theguardian.com/environment/2012/jan/31/china-freshwater-lake-dries-up.

[65]nytimes.com/interactive/2016/07/07/world/americas/bolivia-climate-change-lake-poopo.html.

[66]See https://reliefweb.int/report/iran-islamic-republic/iran-hamun-lake-crisis.

[67]See https://en.wikipedia.org/wiki/List_of_drying_lakes for a detailed list.

[68]See https://en.wikipedia.org/wiki/List_of_drying_lakes for a detailed list.

[69]The Washington Post writes: "The reservoir supplying electricity to 350,000 homes as well as irrigation and drinking water to about 25 million people stands at a record low." See www.washingtonpost.com/climate-environment/2022/06/27/lake-mead-reservoir-drought/.

[70]The Guardian writes: "As drought shrivels Lake Powell, millions face power crisis." See www.theguardian.com/us-news/2022/jul/13/lake-powell-drought-electricity.

[71]The Guardian writes: "California's largest reservoirs at critically low levels – signaling a dry summer ahead." See www.theguardian.com/us-news/2022/jun/24/california-drought-reservoirs-water-levels.

[72]See www.theguardian.com/us-news/2021/oct/13/lake-tahoe-water-level-drought-climate-change.

[73]The Guardian writes: "Paraguay on the brink as historic drought depletes river, its life-giving artery." See www.theguardian.com/global-development/2021/sep/27/paraguay-severe-drought-depletes-river.

[74]In this case, the transformation of the lake is not due to climate change itself but oil slicks. The Guardian writes: "Oil slicks and algae blooms marring Venezuela's largest lake are visible from space." See https://www.washingtonpost.com/world/2021/10/07/oil-pollution-lake-maracaibo-venezuela/.

[75]Associated Press News writes: "Experts say Lake Tuz (Salt Lake in Turkish) is a victim of climate

Moon Lake in Taiwan.[76]; and (v) The Tigris and Euphrates rivers in Iraq.[77]

B Web Data Appendix for the Reduced-Form Analysis

Total surface water area. Total surface water area (sq km) over time was obtained from combining the following main sources: Olivry et al. (1996), Sédick (n.d.), FAO (2009), Comission du Bassin du Lac Tchad (2015), Okpara et al. (2016), and Ighobor (2019).

Chari-Logone River System. The GIS shapefile of the "main rivers" (major rivers) of the Chari-Logone system was obtained from the Landscape Portal. The shapefile for the "other streams" (minor rivers) of the system was obtained from FAO/GeoNetwork.

Water Discharge Rates. The historical water flow data for various sites of the Chari-Logone river system was obtained from DE/FIH/GRDC & UNESCO/IHP.[78]

Temperature & Rainfall. To obtain annual rainfall and average monthly temperature in each subdistrict-year, we use the *Terrestrial Air Temperature and Precipitation: Monthly & Annual Time Series (1900-2017)* V5.01 of Willmott and Matsuura (2001, 2021). The data is reported at a 0.5 by 0.5 degree grid resolution ($\approx$ 55 x 55 km).[79]

C Details on the Chari-Logone River System

Rainfall in the Central African Republic (CAR). While the whole region has been impacted by climate change and declining rainfall, it is the decline of rainfall in the Northern mountainous areas of the CAR that is primarily responsible for the decline in the discharge rate of the Chari and Logone rivers and the lake's water level loss.

As can be seen in the left panel of Web Appx. Fig. C.1, mean annual rainfall (mm) was before 1965 stable in the Northern areas of CAR that correspond to the Chari-Logone river system. We then observe a significant decline starting in 1963, about 200 mm on

change-induced drought, which has hit the region hard, and decades of harmful agricultural policies that exhausted the underground water supply. [...] Several other lakes across Turkey have similarly dried up or have receded to alarming levels [...] Climate experts warn that the entire Mediterranean basin, which includes Turkey, is particularly at risk of severe drought and desertification." See apnews.com/article/climate-science-business-droughts-environment-137e6f52a8fe14db981a45d19e8907d1.

[76] The Guardian writes: "Parched Taiwan prays for rain as Sun Moon Lake is hit by drought. Taiwan's Sun Moon Lake is so low that parts of it have dried and turned to grass." See https://www.theguardian.com/environment/2021/may/09/parched-taiwan-prays-for-rain-as-sun-moon-lake-is-hit-by-drought.

[77] The Washington Post writes that "Where civilization emerged between the Tigris and Euphrates, climate change is poisoning the land and emptying the villages. [...] Years of below-average rainfall have left Iraqi farmers more dependent than ever on the dwindling waters of the Tigris and Euphrates." See https://www.washingtonpost.com/world/interactive/2021/iraq-climate-change-tigris-euphrates/?itid=pr_hybrid_experimentrandom_with_top_mostshared_4_na-ans_4.

[78] Global Runoff Data Center/Federal Institute of Hydrology/Germany, International Hydrological Programme/United Nations Educational/Scientific and Cultural Organization, and Unaffiliated Individual/Byron Bodo. 1985. Monthly Flow Rates of World Rivers (except former Soviet Union). Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D6571974. Accessed 11-15-2021.

[79] Source: http://climate.geog.udel.edu/~climate/html_pages/download.html.

average between the 1950-1964 period and the 1965-1989 period. However, the decline between the early 1960s and the late 1980s is starker, at about 500 mm.[80]

The right panel shows for the four sample countries considered altogether —Cameroon, Chad, Niger, and Nigeria – the patterns for the subdistricts closest to the lake (we consider the subdistricts below the country-specific median Euclidean distance to the lake). A much smaller decline is observed for these areas. As explained later, the post-1965 decline in rainfall was caused by the shrinkage of the lake itself. One can see that the decline in rainfall of these areas started in 1970, at least five years after the rainfall decline in the CAR (1963) and the beginning of the lake's shrinkage (1965).

Evolution of Discharge Rates. We focus our analysis on 8 selected sites of the Chari-Logone River system for which we have historical data on the mean flow rate (m^3/s) from the 1940s to the 1980s. However, the data is only available until 1980 for most of them. See Web Appx. Section B for details on the sources and Web Appx. Figure C.3 for their mapping. Using this data, we can retrace from where the lake's water has disappeared. Since Lake Chad is an endorheic lake, if it is not replenished by the Chari-Logone River system's water, the water evaporates and the lake shrinks. Subfigure (a) of Web Appx. Figure C.3 shows the mean discharge rate at the closest place to the lake, N'Djamena (see Web Appx. Fig. C.3). This is where the Chari and the Logone combine. As seen, the flow rate started decreasing in 1963, consistent with the decline in rainfall also observed in 1963 in the mountainous areas of the Central African Republic (CAR). The discharge rate has since then continuously declined. If we compare the mean discharge rates in 1940-1964 and after 1964 (1965-1990), we observe a loss of 471 m^3/s on average. The question is where the 471 m^3/s come from in the entire river system, and whether we can confidently link this decline to the CAR. We investigate this now by studying discharge rates for seven other sites upstream.

In particular, most of the collapse in N'Djamena came from Bousso rather than Bongor, hence the Chari River rather than the Logone River (see Web Appx. Fig. C.3 for their locations). Indeed, as seen in Subfigure (b), the discharge rate barely changed in Bongor (Logone) between before and after 1964 (loss of 62 m^3/s) while the discharge rate dropped after 1963 in Bousso (Chari; loss of 354 m^3/s). Water from the Chari comes from the CAR as well as the East of Chad. In contrast, the Logone's water comes the CAR via Doba and Cameroon via Mondou (see Web Appx. Fig. C.3). For these two other sites, we also do not observe any significant change between vs. after 1964 (Subfigure (c)). Now, was the Chari's decline explained by river flow decline in the CAR or Chad?

To investigate this, we examine discharge rates in Moissala and Sarh, the entry points of CAR's rainfall into the Chari River, as well as Am Timam, where water only comes from Chad itself (see Web Appx. Fig. C.3). For Moissala and Sarh, we find losses between

[80] Our climate data is reported at a 0.5 by 0.5 degree grid resolution (Web Appx. Section B provides the source). For this analysis, we thus select the 0.5*0.5 degree pixels containing a major river or minor river of the Chari-Logone system. We then take the average of mean annual rainfall across the selected pixels.

vs. after 1964 of 252 and 143 m^3/s, respectively (see Subfigure (d)). In contrast, the loss in Am Timam was 5 m^3/s only (same figure). Therefore, the collapse in Ndjamena came from the CAR, not Cameroon nor Chad. In addition, the decline started in 1963, consistent with the rainfall decline observed in CAR's mountainous areas in 1963.

D Web Data Appendix - City Populations

We focus our compiling effort on localities that reached 5,000 inhabitants at any point during our period of study. Note that we ignore Nigeria due to lack of data.

Niger. In Niger, 166 localities reached 5,000 at least once in 1945-2012. Specifically, we have available city population estimates for the following years: 1945, 1948, 1951, 1955-1962, 1965-1968, 1977, 1988, 2001, and 2012. For the pre-1968 period, we rely on colonial and post-colonial administrative reports of city population sizes. Post-1968, we rely on population censuses (1977, 1988, 2001, 2012). However, information is patchy. When Niger was still a colony as well as just after independence, administrators would sequentially visit various regions at a time to proceed with administrative counts. As such, for 16 localities with more than 5,000 inhabitants before 1968, population is available for different years for different cities. To create a consistent series, we use exponential interpolations. There are then a few cities for which we know their population before the 1940s and in the late 1950s but not in-between. To better estimate their population c. 1950, we also consider their pre-1950 population.

For later years, there are a few cities for which the first population estimate available exceeds 5,000 by several thousands. These cities might have exceeded 5,000 in the previous years of data but we cannot be sure. To allow for this possibility, and for each city without any early estimate, we assume that their 1945 population was 1 inhabitant and use exponential interpolation to fill the missing years. This increases the likelihood that a city exceeds 5,000 if its value is well above 5,000 the following year of data.

Overall, for city-years where the estimated population is not above 5,000, we are confident that population is indeed below that number. Our methodological choices should also not affect the results as few city-years are ultimately concerned.[81]

Finally, total population is available in the years 1951, 1956, 1957 1958, 1959, 1960, 1961, 1962, 1969, 1988, 2001, 2012, 2013, 2014, 2015, 2016 and 2017. We can reconstruct total urban population for many of these. Note that we use city population estimates in 1968 for the year 1969 and ignore 2013-2017 since we do not have city estimates after 2012. In the end, we obtain rural population in 1951, 1956, 1957 1958, 1959, 1960, 1961, 1962, 1969, 1988, 2001 and 2012 (N = 119 subdistricts x 12 years = 1,428 obs.).

Cameroon. 186 localities reached 5,000 at any point in 1945-2005. The available years are 1945, 1950, 1953, 1956, 1958-1968, 1970, 1976, 1987 and 2005. For the pre-1976 years,

[81] For a limited sample of cities, we know their exact population when below 5,000. However, we do not make use of that information due to possible endogenous selection issues in why an estimate is available.

we use colonial and post-colonial administrative counts. For the years 1976, 1987 and 2005, we use population censuses. Total population is available in the years 1963, 1967, 1976, 1987 and 2005. As such, we are able to reconstruct subdistrict rural population for the same years as total population (N = 113 subdistricts x 5 year = 565 obs.).

Chad. 100 localities reached 5,000 at any point in the period 1945-2009. The available years are 1945-1951, 1954-1956, 1961, 1964, 1968, 1975, 1993, 2000, and 2009. For the pre-1968 years, we use colonial and post-colonial administrative counts. For the years 1993 and 2009, we use population censuses. For the years 1975 and 2000, we use administrative population count estimates provided by Chad's *Institute of Statistics*. Total population is available in the years 1948, 1953, 1965, 1993 and 2009. Since we used 1964-1968 total population data for the year "1965", we can reconstruct rural population for the same years as total population (N = 138 subdistricts x 5 year = 690 obs.).

E Web Data Appendix - Model Inputs

Land suitability in agriculture and livestock. We rely on information from the FGGD Digital Atlas of the FAO and IIASA. Their *crop suitability index* (CSI) measures the "suitability of currently available land for rainfed crops, using maximising crop and technology mix." Their *pastoral suitability index* (PSI) measures the suitability of currently available land for pasture. In terms of spatial resolution, "georeferenced data at a resolution of 5 arc-minutes have been used to compile the maps." Thus, the data is reported at a 0.08 by 0.08 degree grid resolution ($\approx$ 9 x 9 km).[82]

Expenditure Shares. For the year 2010, we rely on the World Bank's *Global Consumption Database*. They estimate the shares based several household or budget surveys.[83]

For the year 1965, we cannot rely on national household or budget surveys as such surveys did not exist then. However, there were city-specific surveys as well as region-specific surveys that focused on the regions' rural areas.[84] We first use the city-specific

[82] They consider 171 crops. Url for the data: https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/6a7863d0-892d-11db-b9b2-000d939bc5d8, last accessed 09-01-2021.

[83] Url: https://datatopics.worldbank.org/consumption/, last accessed 07-11-2022. The four surveys used by the World Bank are: (i) Cameroon: Enquete Camerounaise aupres des Menages III 2007; (ii) Chad: Enquete sur la Consommation et le Secteur Informel au Tchad 2003; (iii) Niger: Enquete Nationale sur le Budget et la Consommation des Menages 2007; and (iv) Nigeria: Living Standards Survey 2009.

[84] We use the following sources: (A) Cameroon: (i) Winter, G. (1967). *Methodologie des enquetes "niveau de vie" en milieu rural Africain. Bilan des 3 enquetes effectuees de 1961 a 1965 au Cameroun.* Yaounde: ORSTOM; (ii) Gouvernment du Cameroun (1965). *Etudes Socio-Economiques sur le Nord-Cameroun.* Ministere de l'Economie Nationale, Direction de la Statistique; (iii) Gouvernment du Cameroun (1967). *Enquete sur le niveau de vie a Yaounde - Cameroun 1964-1965.* Direction de la Statistique de la Republique Federale du Cameroun; and (iv) Gouvernment du Cameroun (1967). *Le Niveau de vie des populations de l'Adamaoua.* Direction de la Statistique de la Republique Federale du Cameroun. (B) Chad: Ministere du plan et de la cooperation du Tchad (1969). *Enquete socio-économique au Tchad, 1965.* Paris: Republique francaise, Secretariat d'Etat aux affaires etrangeres: INSEE, Departement de la coopéeration; (C) Niger: (i) Bernus, Suzanne (1964). *Niamey: population et habitat (documents d'enquetes).* Etudes nigeriennes: Doc, IFAN. Republique du Niger; and (ii) Gouvernment du Niger (1962). *Etude démographique du Niger*

survey reports to obtain the expenditure shares for the *urban sector* of each country.[85] We then use the region-specific survey reports to obtain the expenditure shares for the *rural sector* of each country.[86] Lastly, we use the urban share of each country circa 1965 (source: UN (2018)) to obtain the expenditure shares for the whole country.[87]

Finally, using the population of each country in 1965 and 2010 (source: UN (2019)), we obtain the expenditure shares of the overall region. Note that they tend to over-represent Nigeria and Cameroon, the most populated countries in our sample.

The 1965 and 2010 are broadly consistent with each other. However, they also differ for some country-sectors. The 1965 shares have the advantage of being estimated *before* the shrinkage of the lake started. But the 2010 shares are more reliable. Indeed, the 1965 expenditure shares are based on surveys whose methodologies were likely not as consistent as today. Also, the 1965 *national* expenditure shares are reconstructed using an imperfect selection of cities and regions and various assumptions. Measurement error is likely. Given these considerations, we choose the following parameters for each sector: agriculture = 0.35, livestock = 0.10, fishing = 0.10, and urban = 0.45.

Kuri cattle breed data. For each country and circa the year 1965 as much as possible, we obtain the total number of cattle heads in more or less the same areas that had Kuri cattle historically. To do so, we use the following sources for each country: (i) Nigeria (1968): Miller et al. (1968); (ii) Cameroon (early 1970s): Pamo and Pieper (1987); (iii) Niger (1964): Republique du Niger (1964); and (iv) Chad (1966): IBRD (1968).

F Model Parameters

F1. Trade costs-Calibration

To calibrate the trade costs across the different subdistricts we use different sources of information. First, we use the Michelin roads that reports the evolution of the transportation network in Africa considering differences in quality such as paved roads, highways, dirty roads, etc across time and space. We follow the procedure from

(Enquete par sondage, 1960). 1er fascicule : données collectives. Résultats définitifs. Republique du Niger, Mission economique et pastorale; and (D) Nigeria: U.S. Department of Commerce (1964). *Market for U.S. products in Nigeria.* Bureau of International Commerce.

[85] For Cameroon and Nigeria, we rely on 3 and 5 cities, respectively. To obtain an urban average, we use as weights the population of each city circa 1965. For Chad and Niger, since we have only 2 cities in Chad and 1 city in Niger, and given how similar Chad's and Niger's economies and geographies are and were, we combine these 3 cities to obtain an urban average for Chad and Niger combined.

[86] For Cameroon, we have 3 rural regions. To obtain a rural average, we use as weights the population of each region c. 1965. Regional data is unavailable for Nigeria. Since Cameroon is the closest country in terms of economic development as well as physical and economic geography, we use rural Cameroon as a proxy for rural Nigeria. For Chad and Niger, since we have only 1 Southern region in Chad and 2 Northern regions in Niger, and given how similar Chad's and Niger's economies and geographies are and were, we combine these 3 regions to obtain a rural average for Chad and Niger combined.

[87] Since Chad and Niger had slightly different urban shares in 1965, their overall expenditure shares vary even if their "urban" and "rural" expenditure shares do not (since we combine Chad and Niger).

Jedwab and Storeygard (2021) and calculate travel times across subdistricts. For each subdistrict, we use a centroid based on a weighted average using population in 1 degree x 1 degree cells. Table C.7 reports the speeds that we use for the calibration for the movement of goods in Africa. Moreover, we also assume that firms can only move goods from one to another country in specific cities at the border. Figure C.6 shows a map with the locations in which people can cross.

With this information, we calculate the travel times across subdistricts.

Then, to transform travel times to trade costs, we assume a log-linear relationship as in Allen and Arkolakis (2019), Sotelo (2020) and Baldomero-Quintana (2021). In particular, we express the iceberg trade cost as:

$$\tau_{ij} = \exp(\delta t_{ij})(1 + tariff_{ij}),$$

where t_{ij} is the travel time between locations i and j using the road network. To estimate the parameter δ, we use the classic structure of trade models. The price charged by firms in location i to consumers in j is:

$$p_{ij} = p_{ii}\tau_{ij},$$

where p_{ii} corresponds to the original price in location i. This implies that differences in prices of the same product across locations reflect differences in trade costs. Based on this, we collect information on prices in different cities for imported goods in Cameroon and for oil and gas in Niger during the 1960s. In the case of Cameroon, the port of entry is Port Douala, and in the case of Niger, the place of production is Gaya. We calculate travel times between the different cities, and these two places and estimate the following regression:

$$\ln p_{oj} = \underbrace{\alpha}_{p_{oo}} + \delta t_{oj} + \gamma \ln pop_j + \epsilon_{oj}, \tag{10}$$

where o is a subindex of origin: Port Douala or Gaya, t_{oj} is the travel time in hours of moving goods from o to j using the transportation network in 1960, and ϵ_{oj} is the error term. In some of our specifications we also control for the population, and given potential endogeneity concerns for the location of the transportation network, we also instrument travel times with the euclidean distance between the origin and destination. Table C.8 reports the results.

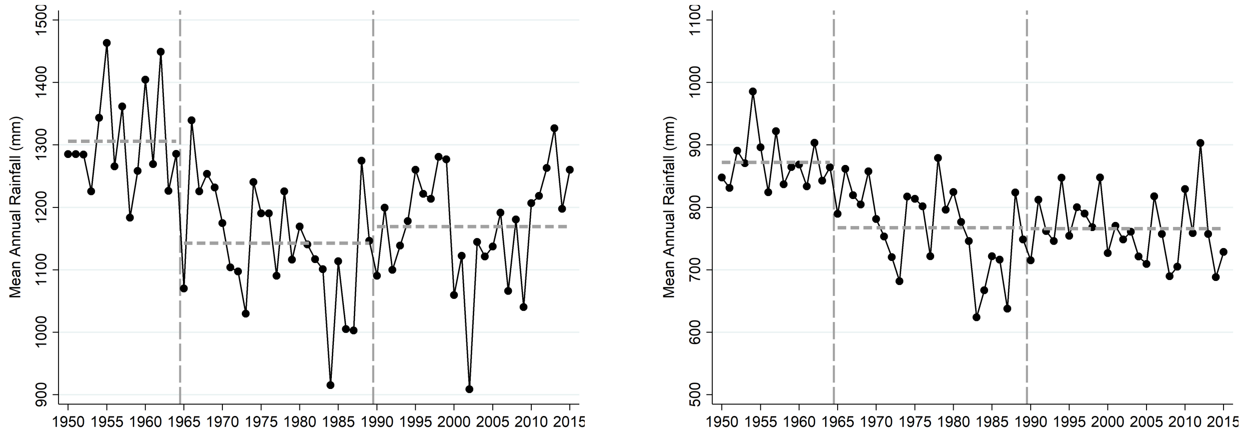
The odd columns report the OLS, while the even columns report the IV. Overall, we find a value for δ between 0.7 and 0.9 that is robust across the different specifications. This is a similar value that other studies have found in other contexts for goods transportation. For example, Allen and Arkolakis (2019) for the US, Sotelo (2020) for Perú, and Baldomero-Quintana (2021) for Colombia. Then, we transform travel times to trade costs for the simulations taking an average and using a value of 0.8.

C. Web Appendix Figures and Tables

Figure C.1: Mean Annual Rainfall in the Central Afr. Rep. vs. the Sample Countries

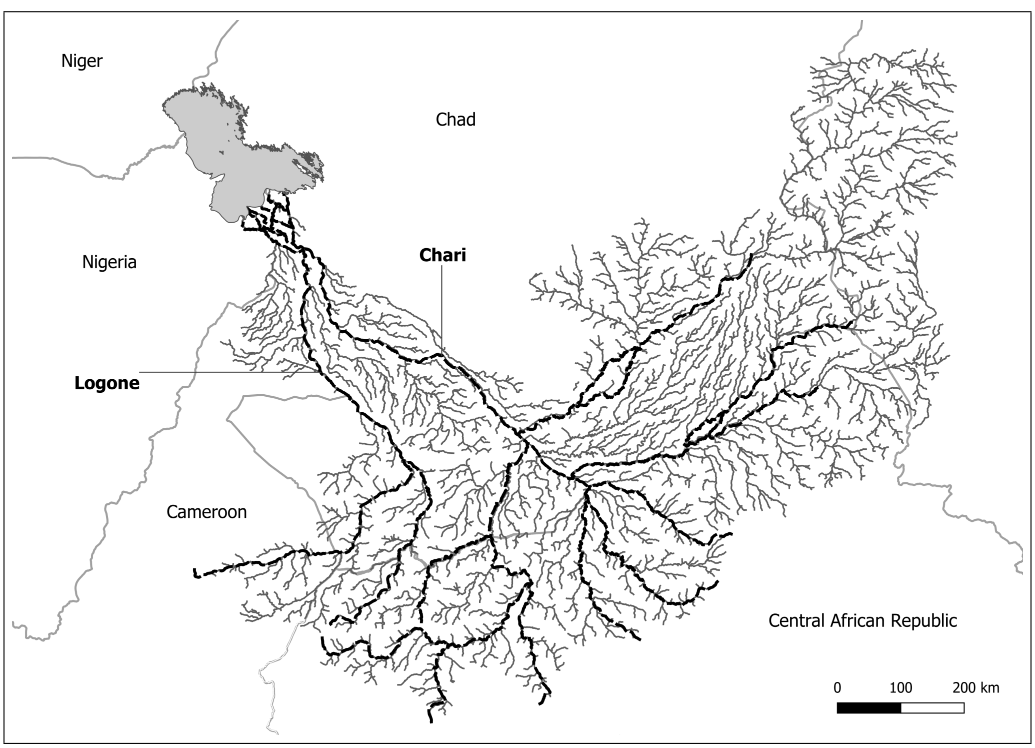
(a) Central African Republic: Areas of the Chari-Logone River System that Feeds Lake Chad's Water

(b) Four Countries of Study: Subdistricts Below the Country-Specific Median Distance to the Lake



Notes: The figures show mean annual rainfall (mm) in each year t: (a) for the areas of the Central African Republic located within 10km of any of the major or minor river of the Chari-Logone river system; and (b) for the subdistricts of Cameroon, Chad, Niger and Nigeria that are close to Lake Chad, i.e. for the subdistricts whose Euclidean distance to the lake is below the median Euclidean distance to the lake in the sample in each country. See Web Data Appendix Section B for details on the sources.

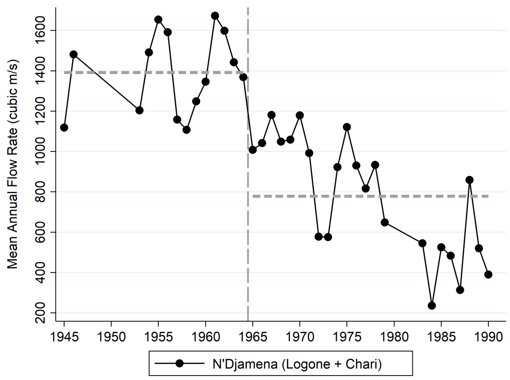
Figure C.2: Chari-Logone River System Feeding Lake Chad, Including Minor Rivers



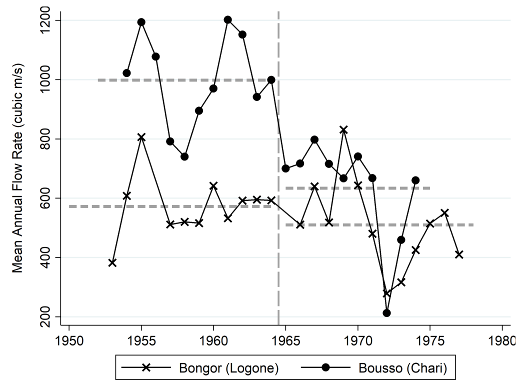
Notes: The Chari and Logone rivers provide almost all of Lake Chad's water. We show in bold the main rivers of the Chari-Logone river system. In grey, we show other streams associated with the Chari-Logone river system. See Web Data Appendix Section B for details on the sources.

Figure C.3: Mean Annual Flow Rate (mm) at Various Sites, 1940s-1980s

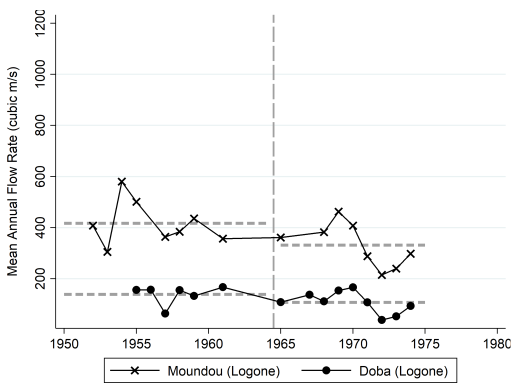
(a) N'Djamena (Chari + Logone)



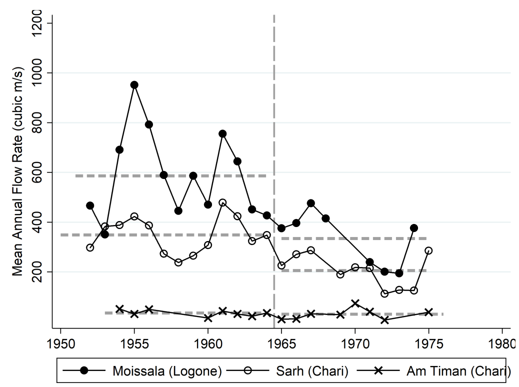
(b) Bongor (Logone) vs. Bousso (Chari)



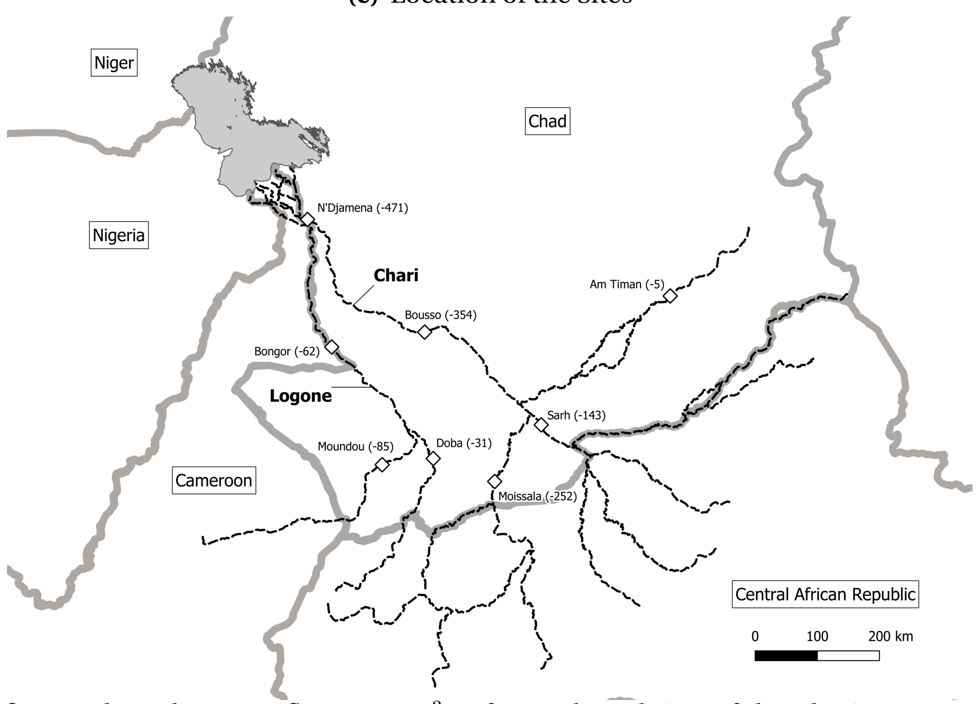
(c) Upstream Sites of Bongor (Logone)



(d) Upstream Sites of Bousso (Chari)



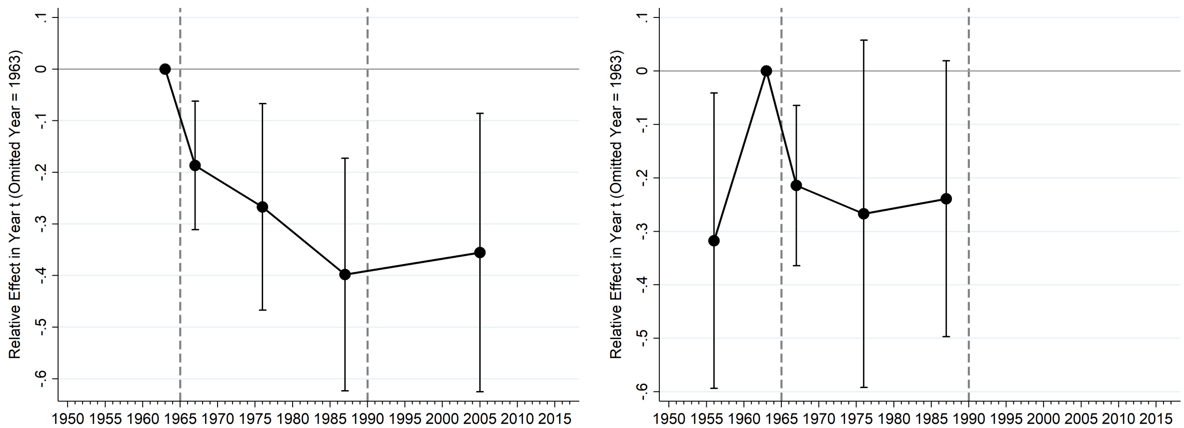
(e) Location of the Sites



Notes: The figures show the mean flow rate (m^3/s) for 8 selected sites of the Chari-Logone river system and for each year with available data and focusing on the 1940s-1980s. We also report the average of the mean rates for each site and each period 1940-1964 and 1964-1990 (for figures (b), (c) and (d), we focus on 1964-1980 due to lack of data in the 1980s). Figure (e) shows the main rivers of the system and the location of the sites. See Web Appx. Sections B and C for details on the sources and analysis, respectively.

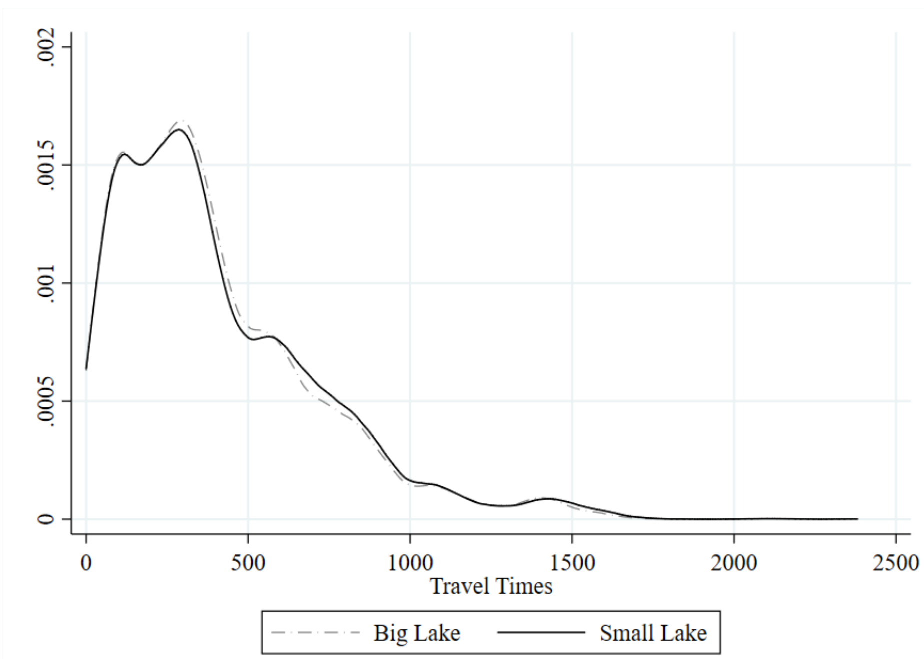
Figure C.4: Relative Population Effect of Proximity to Lake Chad, Cameroon, Pre-Trends

(a) Cameroon Subdistricts (N=113) (1963-2005) **(b)** Cameroon Districts (N=47) (1956-2005)



Notes: Subfigure (a) shows for Cameroonian subdistricts the relative total population effects of proximity to Lake Chad (omitted year = 1963). Subdistrict sample (1963-2005): 113 subdist. x 5 yrs = 565. We include subdistrict and year FE, district-specific linear trends, and time-invariant controls interacted with year FE: log Euclidean distances to the largest and capital cities and their square, latitude, and two dummies for whether the subdistrict contains major or minor rivers of the Logone-Chari river system. Subfigure (b) shows for Cameroonian districts the relative total population effects of proximity to Lake Chad (omitted year = 1963). District sample (1956-2005): 47 dist. x 6 yrs = 282. We include district and year FE, district-specific linear trends, and the time-invariant controls interacted with year FE. With district trends, the district-level effect for the year 2005 is not estimated. The dashed vertical lines show the years the lake started to decline (c. 1965) and recover (c. 1990). 90% confidence intervals (Conley SEs 100 Km).

Figure C.5: Travel Time Distribution: Locations Close to the Lake



Notes: This figure plots the travel time distribution using the methodology from Jedwab and Storeygard (2021) for the subdistricts close to the lake. We assign a speed of 10 kph if a boat transport goods through the lake, and 3 kph in the areas in which the lake disappeared (we use 3 kph, below the typical walking speed, because it is more difficult to walk in such areas, as they tend to be marshy).

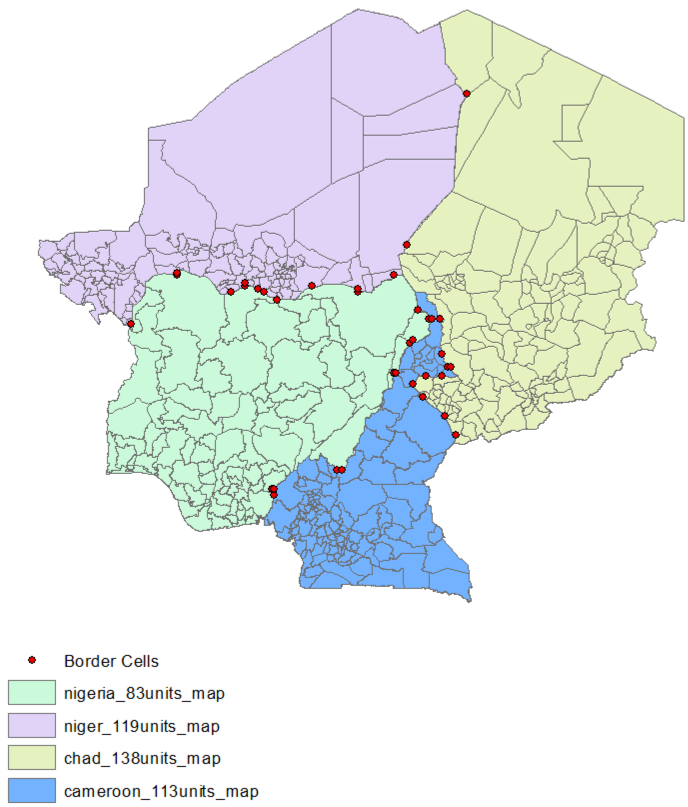
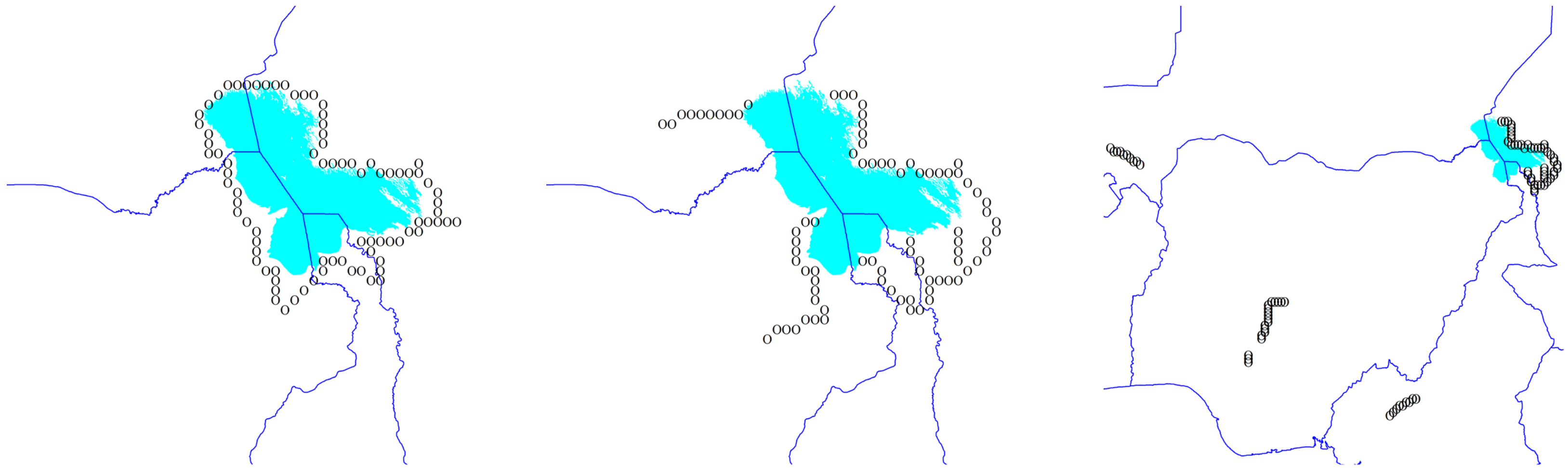
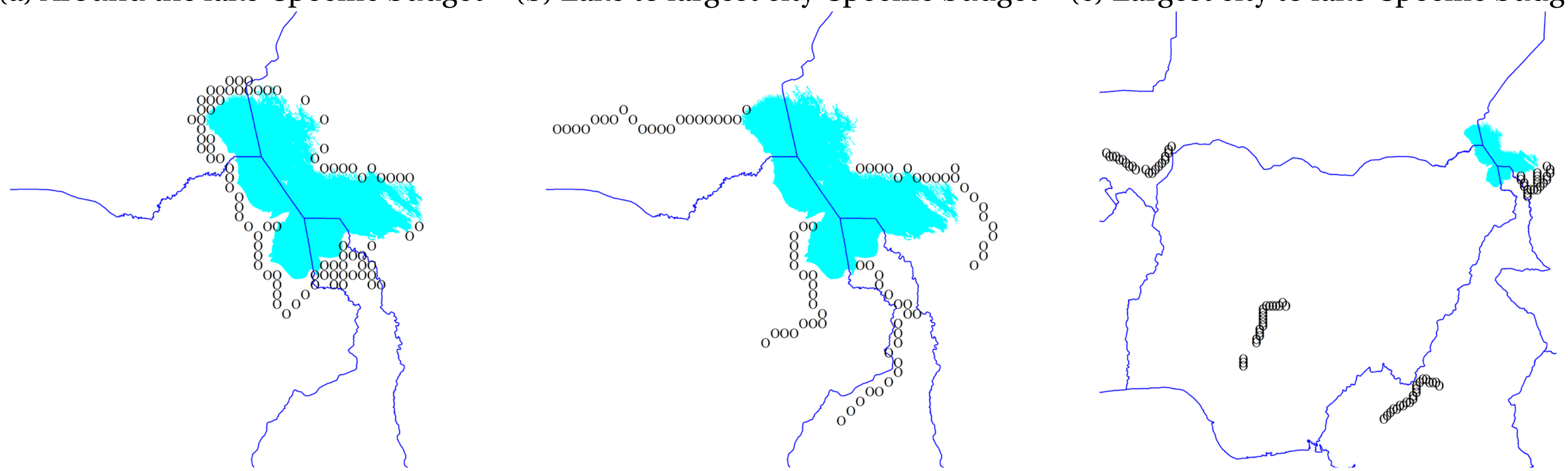


Figure C.6: Border cities

Figure C.7: Policy Simulations - Road Investments - Country-Specific Budget or Same Budget



(a) Around the lake-Specific budget (b) Lake to largest city-Specific budget (c) Largest city to lake-Specific budget



(a) Around the lake-Same budget (b) Lake to largest city-Same budget (c) Largest city to lake-Same budget

Notes: These figures show the (as of 1965) unpaved 0.1*0.1 degree grid cells that are paved in different policy scenarios. In total, we pave 83 unpaved cells under different scenarios in which we either consider country-specific budgets based on the lake's shoreline in each country (Chad = 45 cells; Nigeria = 19; Niger = 10; Cameroon = 9) or a policy where each country receives the same budget of 21 cells (Chad = 21 cells; Nigeria = 21; Niger = 21; Cameroon = 21). Panel (a) shows the cells that are paved around the lake for the country-specific budget case, panel (b) the cells that are paved from the lake to the largest city under the country-specific budget case, and panel (c) the cells from the largest city to the lake under the country-specific case. Similarly, panel (d), (e), and (f) shows the cells that are paved under the same-budget scenario.

Table C.1: **Effect of Proximity to the Lake, Total Population, Cameroon 1960s-2010s**

Dependent Variable:	Log Subdistrict Population in Year t			
Test:	Baseline	Full Lake Centroid	Climate Controls	Conley SE 250 Km
(Relative to the Omitted Year = 1963)	(1)	(2)	(3)	(4)
Proximity to Lake (log)*c.1990 ($t = 1987$)	-0.40***	-0.80***	-0.47***	-0.40**
	[0.14]	[0.27]	[0.15]	[0.18]
Proximity to Lake (log)*c.2010 ($t = 2005$)	-0.36**	-0.72**	-0.34**	-0.36**
	[0.16]	[0.34]	[0.17]	[0.17]
Subdistrict (113) FE, Year (5) FE	Y	Y	Y	Y
District (47) Trends, Controls	Y	Y	Y	Y

Notes: 113 subdistricts x 5 years (1963-2005) = 563 obs. For each subdistrict centroid, *Proximity to Lake (log)* is the negative of the log Euclidean distance to the selected lake centroid. We only report the coefficients for the closest years to the years 1990 and 2010. Except in col. (2), the lake centroid that we use is the centroid of Lake Chad within Cameroon's territory (see Fig. 5). Col. (2): We use the centroid of the full lake. Col. (3): We control for log mean annual rainfall and log mean temperature in the period $[t\text{-}2; t]$. In addition to the district-specific linear trends, we include the following time-invariant controls interacted with year FE: log Euclidean distances to the largest city (Douala) and capital city (Yaoundé) and their square, latitude, a dummy if the subdistrict contains a major of the Chari-Logone river system, and a dummy if it contains a minor river of the river system. Conley SEs 100 Km (col. (4): use 250 km).

Table C.2: **Effect of Proximity to the Lake, Total Population, Nigeria 1950s-2010s**

Dependent Variable:	Log Subdistrict Population in Year t				
Test:	Baseline	Full Lake Centroid	Other Inflow River Control	Climate Controls	Conley SE 250 Km
(Relative to the Omitted Year = 1963)	(1)	(2)	(3)	(4)	(5)
Proximity to Lake (log)*c.1990 ($t = 1991$)	-0.47***	-0.54***	-0.46***	-0.52***	-0.47***
	[0.16]	[0.18]	[0.17]	[0.18]	[0.11]
Proximity to Lake (log)*c.2010 ($t = 2006$)	-0.37*	-0.42*	-0.49**	-0.38*	-0.37***
	[0.19]	[0.22]	[0.21]	[0.20]	[0.12]
Subdistrict (83) FE, Year (4) FE	Y	Y	Y	Y	Y
District (24) Trends, Controls	Y	Y	Y	Y	Y

Notes: 83 subdistricts x 4 years (1952-2006) = 332 obs. For each subdistrict centroid, *Proximity to Lake (log)* is the negative of the log Euclidean distance to the selected lake centroid. We only report the coefficients for the closest years to the years 1990 and 2010. Except in col. (2), the lake centroid that we use is the centroid of Lake Chad within Nigeria's territory (see Fig. 5). Col. (2): We use the centroid of the full lake. Col. (3): We add a dummy if the subdistrict contains the Komadugu-Yobe river, which we then interact with year FE. Col. (4): We control for the log of mean annual rainfall and the log of mean temperature in the period $[t\text{-}2; t]$. In addition to the district-specific linear trends, we include the following time-invariant controls which we interact with year FE: log Euclidean distances to the largest city (Lagos), the capital city (Abuja), the capital city of the North (Kano), the informal capital cities of the oil-producing Delta region (Port Harcourt and Benin City), and their square, a dummy if the subdistrict contained oil reserves c. 1960, latitude, a dummy if the subdistrict contains a major of the Chari-Logone river system, and a dummy if the subdistrict contains a minor river of the river system. Conley SEs 100 Km (col. (5): we use 250 km).

Table C.3: **Effect of Proximity to the Lake, Total Population, Chad 1940s-2010s**

Dependent Variable:	Log Subdistrict Population in Year t				
Lake Centroid:	Baseline Chad North	Chad Full	Chad South	Chad North vs. South: Chad North	Chad North vs. South: Chad South
(Relative to the Omitted Year = 1965)	(1)	(2)	(3)	(4)	
Proximity to Lake (log)*c.1990 (t = 1993)	-0.54***	-0.33**	-0.18**	-0.71**	0.19
	[0.08]	[0.15]	[0.08]	[0.31]	[0.231]
Proximity to Lake (log)*c.2010 (t = 2009)	-0.62***	-0.48***	-0.38***	-0.47***	-0.29
	[0.17]	[0.16]	[0.10]	[0.13]	[0.206]
Subdistrict (138) FE, Year (5) FE	Y	Y	Y	Y	
District (36) Trends, Controls	Y	Y	Y	Y	
Test:	Chad North vs. Fitri: Chad North	Chad North vs. Fitri: Chad Fitri	Outflow Control	Climate Controls	Conley 250 Km
(Relative to the Omitted Year = 1965)	(5)		(6)	(7)	(8)
Proximity to Lake (log)*c.1990 (t = 1993)	-0.48***	0.17	-0.50***	-0.52***	-0.54***
	[0.10]	[0.12]	[0.08]	[0.09]	[0.06]
Proximity to Lake (log)*c.2010 (t = 2009)	-0.57***	0.16	-0.54***	-0.63***	-0.62***
	[0.17]	[0.14]	[0.15]	[0.17]	[0.13]
Subdistrict (138) FE, Year (5) FE	Y		Y	Y	Y
District (36) Trends, Controls	Y		Y	Y	Y

Notes: 138 subdist. x 5 years (1948-2009) = 690 obs. For each subdistrict centroid, *Proximity to Lake (log)* is the negative of the log Euclidean distance to the selected lake centroid. We only report the estimated coefficients for the closest years to the year 1990 and the year 2010. In col. (1), the lake centroid that we use is the centroid of the Northern section of the lake that belongs to Chad's territory (see Fig. 5 for details). In col. (2), we use the centroid of the full lake area within Chad's territory (Ibid.). In col. (3), we use the centroid of the Southern section of the lake that belongs to Chad's territory. In col. (4), we use both the Northern and Southern centroids. In col. (5), we also consider the centroid of Lake Fitri which is fully contained within Chad's territory (see Fig. 6 for the location of Lake Fitri in Chad). In col. (6), we add a dummy if the subdistrict contains the Bahr el-Ghazal – a dry riverbed that was before the 1940s an outflow river of Lake Chad – which we interact with year FE. Col. (7): We control for the log of mean annual rainfall and the log of mean temperature in the period $[t\text{-}2; t]$. In addition to the district-specific linear trends, we include the following time-invariant controls which we interact with year FE: log Euclidean distance to the largest/capital city (N'Djamena) and its square, latitude, a dummy if the subdistrict contains a major of the Chari-Logone river system, and a dummy if the subdistrict contains a minor river of the Chari-Logone river system. Conley SEs 100 Km (except in col. (8) where we use 250).

Table C.4: Expenditure Shares for Each Country, Circa 1965 and Circa 2010

Circa 1965	Cameroon	Chad	Niger	Nigeria	Pop.-Wtd Avg
Year:	1961-65	1960-65	1960-65	1955-65	1955-65
Agriculture	0.33	0.49	0.50	0.32	0.34
Livestock	0.13	0.14	0.15	0.13	0.13
Fishing	0.13	0.10	0.09	0.12	0.12
Urban	0.41	0.27	0.26	0.43	0.41
Circa 2010	Cameroon	Chad	Niger	Nigeria	Pop.-Wtd Avg
Year:	2007	2003	2007	2009	2003-09
Agriculture	0.31	0.56	0.49	0.45	0.45
Livestock	0.06	0.09	0.05	0.06	0.06
Fishing	0.04	0.03	0.00	0.05	0.05
Urban	0.59	0.32	0.46	0.43	0.44

Notes: Comparing the circa 1965 and circa 2010 expenditure shares, we choose agriculture = 0.35, livestock = 0.10, fishing = 0.10, and urban = 0.45. See Web Appx. Section E for details on the sources.

Table C.5: Selected Factor Intensities

Sector	**Labor share**	**Land share**	**Water share**
Agriculture	0.40	0.60	0.0
Livestock	0.30	0.70	0.0
Fishing	0.30	0.0	0.70
Urban sector	0.70	0.30	0.0

Notes: This table reports the factor intensity shares from Pellegrina (2022). See text for details.

Table C.6: Main Elasticities

Parameter	**Value**	**Paper**
Trade Elasticity	5	Simonovska and Waugh (2014)
Migration Elasticity	2	Monte et al. (2018)
Urban Agglomeration Externalities	0.1	Ahlfeldt et al. (2015); Bartelme et al. (2019)
Congestion Force	0, 0.32	Desmet et al. (2018)
Exp. Share in Housing	0.25	Household survey data

Notes: This table reports the values of the main elasticities that we use to compute the counterfactuals.

Table C.7: Speeds (Kms/hour)

Category	**Speed**
Highway	80
Paved road	60
Improved road	40
Dirt road	12
Lake	10
No road	3

Table C.8: Estimation of trade costs c. 1965

	(1)	(2)	(3)	(4)
	Panel A: Imported goods-Cameroon			
VARIABLES	$\ln p_{oj}$	$\ln p_{oj}$	$\ln p_{oj}$	$\ln p_{oj}$
t_{ij}	0.089***	0.090***	0.088***	0.090***
	(0.006)	(0.006)	(0.006)	(0.005)
$\ln pop_j$			-0.027***	-0.027***
			(0.007)	(0.007)
Observations	48	48	48	48
R-squared	0.815	0.815	0.851	0.850
F-statistic		524		518
	Panel B: Oil and gas-Niger			
VARIABLES	$\ln p_{oj}$	$\ln p_{oj}$	$\ln p_{oj}$	$\ln p_{oj}$
t_{ij}	0.068***	0.064***	0.072***	0.069***
	(0.008)	(0.008)	(0.008)	(0.008)
$\ln pop_j$			0.017*	0.015*
			(0.009)	(0.009)
Observations	19	19	19	19
R-squared	0.803	0.801	0.836	0.834
F statistic		456		392