Keep Off the Grass: Grassland Scarcity and the Security Implications of Cross-Border Transhumance Between Niger and Nigeria

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Abstract

In 2018, 1,300 people were killed and 300,000 displaced as a result of herder-farmer conflicts in Nigeria. These tensions threaten the already weakened security, economic development and food security in Western Africa. Indeed, cross-border transhumance of herders during the dry season is an important economic activity recognized by the Economic Community of West African States (ECOWAS). This practice is also an important adaptation strategy to climate change for the Sahelian States who developed a comparative advantage in producing and exporting of livestock with their neighbors. However, the establishment of a harmonized legal framework surrounding this practice is hampered by coordination failures between Coastal States (primary receivers of livestock flows) and the Sahelian States (primary providers of livestock flows). The growth of the Nigerian agricultural sector through the expansion of agricultural land threatens the last open pastures and transhumance corridors. Indeed, Nigeria faces a scarcity of arable land for a growing rural population. Is competition for the remaining Nigerian grassland a factor of violence between nomadic herders from Niger and Nigerian farmers? Recent empirical evidence suggests that climate-induced migration of herders in nearby agricultural areas (short transhumance) is associated with a higher risk of herder-farmer conflict for the remaining pastoral resources. However, no analysis has been made on the case of lengthy and costly transhumance. This article analyses the security implications of cross-border transhumance between Niger and Nigeria at the scale of 0.5x0.5 degree cells between 2006 and 2016. Using spatial panel techniques and satellite data on land cover, it questions the importance of grassland grabbing strategies as a cause of the recent herder-farmer conflicts in Nigeria.

1 Introduction

Many West African countries are experiencing a surge in conflicts involving local pastoralists and farmers (Higazi and Abubakar Ali, 2018). They mostly appear in coastal States following the partial or total destruction of agricultural land on the passage of herds in transhumance. Over the last years, herder-farmer conflicts have taken more lives in Nigeria than in all ECOWAS countries combined (Higazi and Abubakar Ali, 2018). In 2018, more than 1,300 people were killed and 300,000 displaced in Nigeria because of herder-farmer violence (ICG, 2018). On December 3, 2019, the Economic and Social Council and the United Nations Peacebuilding Commission met to discuss cross-border transhumance's economic and security impact in West Africa. This traditional activity, which is linked to the climatic constraints in the Sahel, divides West African countries around the economic benefits of regional integration and the security risk associated with the movement of people and their goods across borders.

The Economic Community of West African States (ECOWAS) recognizes transhumance as an economically and socially important adaptation strategy to climate change. For several Sahelian countries, pastoralism is the only possible activity in the vast arid spaces near the Sahel. This environment-induced specialization gives them a comparative advantage in supplying livestock and livestock-related products to coastal countries.[1] However, the amount of Sahelian pastures fluctuates with climatic conditions, making seasonal migration to the Coastal States the primary adaptation mechanism of Sahelian pastoralists to the depletion of pastures during the dry season. Cross-border transhumance involves seasonal and cyclical migration of herders and their cattle in complementary ecological areas beyond national borders. This practice supplies 65% of cattle meat in Western Africa (Kamuanga et al., 2008) and has proven to be highly resilient to the economic and ecological challenges of the region (Ducrotoy et al., 2016; Leonhardt, 2019). Nigeria imports a large proportion of its meat from neighboring countries[2], particularly Niger through transhumance. During the rainy season (between June and September), both Nigerien and Nigerian nomadic herders take advantage of Nigerien grasslands. During the dry season (between October and May), the herders and their cattle travel several hundred kilometers[3] to the South (in Nigeria), searching for water and pasture.

During transhumance, the herder seeks to maximize the health and size of his herd by reaching successively pastoral resources, knowing that movement has a cost and his information on the localization of grassland over the Nigerian territory is imperfect. Recent empirical work analyzes how climate-motivated migration of herders affects the risk of herder-farmer conflict in Africa (Eberle et al., 2020; McGuirk and Nunn, 2020). Sudden climatic shocks affecting the depletion of grazing resources in pastoral areas can increase the number of herders resorting to transhumance. These movements are associated with a higher risk of herder-farmer conflict in nearby transition areas (i.e., areas suited for agricultural and pastoral activities) as they disrupt tra-

[1] See, for example, https://www.worldbank.org/en/news/press-release/2021/03/30/world-bank-provides-375-million-to-boost-efforts-towards-realizing-the-full-potential-of-pastoralism-in-the-sahel, accessed April 2021.

[2] In Nigeria, the livestock sector's contribution to the GDP is around 1.7% (FAO, 2019).

[3] Some breeders practice "great nomadism" and cover more than 1000 km (Dia and Duponnois, 2013; Thébaud et al., 2018; Apolloni et al., 2019). Also, transhumance to the southern parts of Nigeria is more frequent since the decline in trypanosomiasis prevalence.

ditional informal arrangements between herders and farmers on land use. The authors are interested in migration between a cell (of approximately $55x55$ kilometers at the equator) and its direct neighboring cells (i.e., "short" migration). Empirically, the herder's itinerary for these short migrations is defined by one area of origin (a pastoral zone) and one destination (a neighboring transition area). In the case of cross-border transhumance between Niger and Nigeria, the itinerary involves one departure area (a pastoral zone in Niger), several destination zones (pastures in Nigeria), and several "transit areas" between them. Conflicts appearing at the destination (where the resource is) may be linked to a competition for the resource in a context of destabilized traditional arrangements. Nonetheless, conflict can appear during transit if the departure and destination are far away. Indeed, the absence of continuous access to pastoral resources can force herders to practice crop encroachment or buy crop residues[4] to avoid costly animal diseases or deaths during a long transit. The induced proximity of pastoralists to agricultural areas could increase the risk of herder-farmer conflict.

This article analyzes the economic mechanisms linking climate-related seasonal migration of herders from Niger to conflict with Nigerian farmers. The study of spatial spillovers rising from the localization of the remaining pastures in Nigeria contributes to the recent literature on herder-farmer conflict by exploring the motivations of involved actors. Are herder-farmer conflicts caused by competition for the remaining grasslands or by reducing the opportunity cost of violent appropriation of nearby lower quality grazing resources? Our empirical strategy relies on highly disaggregated information (at the scale of 0.5x0.5 degree latitude and longitude) on land covers, climatic conditions, and cattle grazing clashes in Nigeria. It includes a rich set of fixed effects to rule out competing political, ethnic, and religious mechanisms.[5] This article provides a detailed analysis of the heterogeneous effect of climatic conditions in Niger's grasslands during the rainy season on the risk of herder-farmer conflict in Nigeria during the following dry season. It also analyzes the legal and political framework surrounding nomadic pastoralism at the national (i.e., in Niger and Nigeria) and regional scale (i.e., in the ECOWAS region), highlighting diverging views and ambitions for this practice. This article also contributes to the literature on the effect of resource scarcity on the risk of conflict (De Soysa, 2002; Magnus Theisen, 2008; Urdal, 2005; Almer et al., 2017; Vesco et al., 2020) and the literature on the effect of climate on conflict (Benjaminsen et al., 2012; Fjelde and von Uexkull, 2012; Hendrix and Salehyan, 2012; Harari and Ferrara, 2018).

The remainder of this paper is organized as follows. Section 2 presents the legal framework surrounding cross-border transhumance between Niger and Nigeria. In Section 3, we present the literature and theoretical motivations of this analysis. Section 4 describes the main data. Section 5 presents the empirical challenges and the empirical strategy associated with this study. Section 6 presents our main results. Some robustness checks are presented in Section 7, and we conclude in Section 8.

[4]In Western Africa, crop residues and wild grasses are increasingly commercialized as pastoral resources by residents. This practice tends to increase the number of herder-farmer clashes (Leonhardt, 2019)."*Under this pressure, conflicts over the modalities of access to pastoral resources are rife. This often shows in conflicts over the determination of the date, by which harvested fields are opened to pastoralists.*", Leonhardt (2019).

[5]It should be noted that this analysis excludes but makes no judgment on the relative importance of these factors as causes of herder-farmer conflicts.

2 Background and Legal Context

2.1 The 1979 ECOWAS Protocol on Free Movement of People and Goods

Niger and Nigeria are members of the Economic Community of West African States (ECOWAS) since 1975. One of the main objectives of ECOWAS is to accelerate regional development by removing obstacles and barriers to the commercial movement of citizens across the artificial borders created by the colonial powers. It has been the only regional organization in Africa that has recognized the economic value of transhumance and passed legislation ensuring regional livestock mobility.

The 1979 ECOWAS Protocol on Free Movement of People and Goods[6] gives ECOWAS citizens the right to enter and reside in the territory of any member state as long as they possess valid travel documents and international health certificates. It also provides member states the right to refuse admission to citizens deemed inadmissible under their national law. Although all ECOWAS countries signed the protocol in 1978, some coastal countries, including Nigeria, have rapidly expressed concern about its implication for national security. The free movement of people and goods across borders could ease criminal activities such as money laundering and traffics (Aduloju and Opanike, 2015). Nonetheless, member states adopt the protocol in 1979 with a three-phase implementation plan: (1) the right of entry and the abolition of visas for stays of less than 90 days; (2) the right of residence after 90 days to seek and exercise income-earning employment; and (3) the right of establishment for companies. Only the first phase was implemented. The application of phases (2) and (3) encountered many obstacles, particularly the two oil shocks' consequences on the Nigerian economy. Since the 1980s, Nigeria has regularly resorted to anti-regionalist policies justified by the desire to protect its economy during downturns. These decisions contravene the ECOWAS initiative. In response to the Nigerian economic crisis of 1983, President Shehu's civil administration expelled one million foreign workers, mostly from neighboring countries (Brown, 1989). After the military coup of Major General Muhammadu Buhari, Nigeria launched a "war against indiscipline"[7] which led it to close and secure its borders from April 1984 till March 1986. Again, in May 1985, over a million foreign workers were expelled from Nigeria.

Additional protocols were adopted between 1985 and 1990[8] to commit the Member States, among other things, not to carry out mass expulsions and limit the ground for individual expulsion to reasons of national security, public order, morality, public health, or non-compliance with an essential condition of residence.[9]

The full implementation of the protocol and free movement of people (with their goods and services) has so far never been fully achieved. Economic and security issues both at the national and regional scale are still a source of divergence between Nigeria and ECOWAS regarding the movements of transhumant herders between

[6] 1979 Protocol A/P.1/5/79 relating to Free Movement of Persons, Residence and Establishment.

[7] Indiscipline refers to illegal activities such as smuggling or currency trafficking.

[8] 1985 Supplementary Protocol A/SP.1/7/85 on the Code of Conduct for the implementation of the Protocol on Free Movement of Persons, the Right of Residence and Establishment; 1986 Supplementary Protocol A/SP.1/7/86 on the Second Phase (Right of Residence); 1989 Supplementary Protocol A/SP.1/6/89 amending and complementing the provisions of Article 7 of the Protocol on Free Movement, Right of Residence and Establishment; and 1990 Supplementary Protocol A/SP.2/5/90 on the Implementation of the Third Phase (Right to Establishment).

[9] Initially, these additions intend to protect the rights of refugees following the civil wars in Liberia, Sierra Leone, and Côte d'Ivoire.

Niger and Nigeria. For example, Nigeria again decided to close its border with Niger and Benin in August 2019 to develop a strategy to stem the fraudulent export of agricultural products across the Nigerian border.

2.2 Recent Policies on Transhumance

ECOWAS

The 1998 ECOWAS Transhumance Protocol[10] recognizes the economic value of transhumance and authorizes it under certain conditions. The right of free passage of animals requires presenting an ECOWAS International Transhumance Certificate for the herd.[11] Member States of the ECOWAS establish predefined routes while the host countries fix the period during which transhumant animals can enter and leave their territory. Since the ECOWAS Transhumance Protocol, Sahelian States like Niger have implemented new legislation on pastoralism and transhumance. The legislation of Nigeria and other coastal States permits cross-border transhumance as defined by the ECOWAS Protocol, but they also seek to restrict and control it by imposing severe conditions on these flows of foreign breeders.

The regulation related to the ECOWAS Protocol's implementation[12] was promulgated in 2003, five years after the protocol was signed. It stresses that pastoral transhumance contributes to socio-economic development and livestock production's growth, but recommends its gradual replacement by intensive animal husbandry methods (without specifying if this involves the sedentarization of nomadic herders). It formalizes the role of member States in dissemination the content of the Transhumance protocol and establishing/strengthening pastoralist organizations, national committees, and networks able to manage and monitor transhumance. Both State members and the ECOWAS were asked to collaborate to improve knowledge, technical and financial support to pastoralism.

In 2005, the ECOWAS elaborated its first Agricultural Policy (ECOWAP). As part of its implementation and following the 2008 food crisis, the Ministers of Livestock, Trade, and Security of the ECOWAS Member States adopted in 2009 the Guiding Principles for the Development of the Livestock Industry within ECOWAS. They recognize the contribution of the livestock sector to food security and economic development in West Africa. Among the guiding principles, the ministers propose to protect pastoral areas and transhumance corridors through the harmonization of pastoral codes and agro-sylvo-pastoral laws implemented. Furthermore, they recommend the strict implementation of the regulation on the free movement of persons, goods, capital, and services (including the right of entry, residence and establishment). The guiding principles were then used by the ECOWAS Commission to prepare a "Strategic Action Plan for the Development and Transformation of the Livestock Sector in the ECOWAS Region (2011–2020)". In contrast to the 1998 Protocol on transhumance, it recognizes transhumance as a way for herders to cope with climate change. They consider that clashes between nomad herders and farmers are due to grazing deficits, ignorance or difficulty in applying the 1998 Protocol on

[10] Decision A/DEC.5/10/98 Relating to the regulations on Transhumance Between the ECOWAS Member States.
[11] This document specifies the composition, the vaccination history and the itinerary of the cattle in the host country.
[12] Regulation C/REG.3/01/03 Relating to the implementation of the regulations on transhumance between the ECOWAS Member States

Transhumance, irrational management of pastoral grazing resources, weak institutional framework, and coordination failures between member states. The ECOWAS envisages a budget of 52 million dollars to secure and simplify the transnational mobility of pastoralists. It plans to coordinate the mapping of pastures and facilitate the use of corridors (40 million), adapt the legislation on transnational transhumance (7 million), and put in place a regional conflict prevention framework (5 million).[13]

Niger

Niger is the largest West African country with a land area of 1,270,000 square kilometers. It is an arid country where only 1% of the territory receives the regular and sufficient rainfall necessary for agricultural production. Because of this climate, Niger has a long tradition of livestock production. 87% of its active population still practice animal husbandry as a primary or secondary source of income, and this sector accounts for 13% of Niger's Gross Domestic Product (GDP) and 40% of its agricultural GDP (Rhissa, 2010). In Niger, mobility is a necessity for all agro-pastoral production systems, given the environmental conditions. It is also an expression of cultural identity and reinforcing social ties between pastoralists and farmers (Leonhardt, 2019).[14]

Among ECOWAS members, Niger's legislation on pastoralism is one of the most advanced (Leonhardt, 2019). Niger's GDP depends on the livestock sector at 8.5% (according to 2018 estimations of Niger's national statistics institute). Since 1993, Niger is developing its Rural Code which guides natural resources' use in rural areas. A multi-tiered institutional structure rules the management of natural resources and the registration of land certificates.[15] The 1993 Nigerien Rural code (1993) defines the use rights for pastoralists according to a division of the territory between land affected to agricultural (in the Southern regions with isohyets superior to 300-400 mm) or pastoral activities (public lands in the North). In the official pastoral areas, herders enjoy collective use rights, and large-scale agricultural activity is prohibited (farmers cannot expect compensation for damage on unauthorized fields). To facilitate the cohabitation of farmers and herders in the South, the Rural Code introduces private land ownership for farmers and defines pastoral enclaves (transhumance corridors and grazing areas) for exclusive pastoral use.

The 2010 Ordinance on pastoralism reaffirms several prerogatives of the 1993 Rural Code. It guarantees and recognizes nomadic pastoralism as a fundamental right and prohibits the granting of land concessions in pastoral areas if they obstruct pastoralists' movement. Transhumance is recognized as a sustainable and efficient way of using pastoral resources. Also, all pastoral lands are classified as public domain and protected from agriculture occupation. The ordinance gives herders the right to graze their herds in agricultural zones after harvesting of rain-fed produce. In the case of crisis, including drought-related pasture scarcity, pastoralists are

[13] The ECOWAS budget also includes developing a sub-regional transhumance charter and establishing a transhumance observatory.

[14] In recent decades, most pastoralists and farmers have diversified their production systems by combining agriculture and animal husbandry. For the Fulani people (approximately 7% of the Nigerien population), breeding is part of their identity and constitutes cultural heritage. Although they now also combine cattle breeding with a certain degree of agriculture and have mostly settled down, they continue to practice transhumance, which involves moving the herds to the South during the dry season to access water points and pastures.

[15] There is the National Committee of the Rural Code at the ministerial level, the permanent secretary of the Rural Code at the national and regional level, and land commission at community and departmental levels.

authorized to use public ranches and protected forests as an emergency refuge for their cattle. In case of damage on agricultural lands, the Land Commission determines compensation for the farmer that cannot exceed the value of the loss. In case of animal abuse, herders are also eligible for financial compensation according to the animal's value on the livestock market. The 1993 Rural code and the 2010 Ordinance on pastoralism provide a legal framework intending to reduce competition over land between herders and farmers. It indicates a political will to recognize and protect pastoral activities, including transhumance. However, the operationalization of the 2010 ordinance is still in progress. In 2017, only a few decrees were adopted out of the 14 necessary ones.

Nigeria

The Nigerian economy is dependent on the oil sector (Ross, 2003).[16] This dependency can be detrimental to its economic development because oil abundance can be associated with a natural resource curse (Sala-i Martin and Subramanian, 2013). Oil rents can affect the political and administrative environment and hamper long-term growth by inducing rent-seeking and corruption. It also expose the country to commodity price volatility and Dutch Disease (i.e., appreciation of the real exchange rate in case of positive shocks). The 1972 Nigerian Enterprises Promotion Decree (also referred as the Indigenization Decree) is generally presented as the first step of Nigerian government into the import substitution industrialization (ISI) strategy (Ezeji and Okonkwo, 2014). This type of policy aims at reducing a country's dependency on foreign imports by improving domestic production. The Decree had mixed results, especially for the agricultural sector. Before the mid 1970s, the agricultural sector contributed to over 60% of the GDP and 95% of the Nigerian food needs (Osuntokun et al., 1997). In the 80's, Nigeria turned from a net exporter of agricultural products to a net importer of food items (Akanle et al., 2013). Successive governments implemented various strategies to improve the balance of trade, but Nigeria is still a heavy importer of food item, including meat[17].

Nigerian legislation has tried for many years to sedentarize transhumant pastoralists to develop intensive livestock ranches, reduce meat imports, and stop conflicts between herders and farmers over grazing lands. In 1942, the "Fulani Settlement Scheme" is the first attempt of Nigeria to sedentarize transhumant pastoralists. Pastoralist households were allocated plots in Plateau State while being encouraged to practice mixed farming.[18] Through the Grazing Reserve Act of 1965, Nigeria tried simultaneously to sedentarize pastoralists (particularly the Fulani) and improve their access to grazing lands and essential equipment. It empowered the Ministry of Animal and Forestry Resources to acquire, preserve, control, and manage grazing resources. It also paved the way for the creation of transhumance routes linking the reserves together. The National Agricultural Policy of 1988 was a second step in this direction. It stipulates that at least 10% of the Nigerian territory (9.8 million acres) would be allocated to grazing reserves. Between 1970 and 1980, nearly 50 million USD were invested by federal and state governments to establish grazing reserves, while the World Bank and USAID provided fi-

[16] Between 1970 and 1999, the Nigerian petroleum industry generated about 231 billion dollars in rents, while average income per capita fell from 264 to 250 dollars a year (Ross, 2003).

[17] See, for example, https://www.bbc.com/news/world-africa-49367968, accessed April 2021.

[18] The Scheme was finally considered too expensive, and the plots have quickly been replaced by tin mines (Leonhardt, 2019).

nancial support to the equipment and operationalization of the selected reserves. By 1980, less than 1 million acres were established as pasture reserves (10% of the planned size). Today, there are 415 grazing reserves in Nigeria, but only a third are used (Leonhardt, 2019).

Buhari made agricultural development an argument for his 2015 and 2019 election campaigns. However, several challenges remain to achieve independence on meat imports, including population growth, international oil price volatility, and security issues (causing population displacement, isolation from local markets, and human and capital losses). In 2015, a "Special Committee on Strategic Action Plan for the Development of Grazing Reserves and Stock Routes Nationwide" was set up by the recently elected president Buhari to propose solutions to the increasing number of clashes between herders and farmers. In 2016, the committee presented a National Grazing Reserve (Establishment) Bill to the parliament. They proposed establishing a National Grazing Reserve Commission responsible for the identification and acquisition of lands to establish grazing reserves. The Senate rejected the bill since grazing reserves establishment relates to zoning and planning laws that are primarily state and local issues. Indeed, the land tenure system and property rights in Nigeria are defined by the 1999 Constitution and the Land Use Act (LUA) of 1978, which handed over the management of land to state governors (Ele, 2020). In response to the government's proposal to establish grazing reserves in all states, some of them introduced particularly hostile laws against the establishment of pasture reserves and transhumant herding. For example, Benue and Taraba states introduced legislation in 2017 banning open grazing in their territories to stop herders/farmers conflicts. Either in the current "Agricultural Promotion Policy" (2016-2020) or the "National Ranching Development Plan" of 2017, pastoralism transhumance is seen as a threat to national security while intensive ranching is presented as the only future for livestock production in Nigeria.

3 Theoretical Motivations

Academics often present disputes involving nomad pastoralists and sedentary farmers as illustrations of "resource scarcity conflicts" associated with the diminishing number of grasslands (for a review, see Turner, 2004). Homer-Dixon (1999) theorizes resource scarcity conflict as violence caused by the scarcity of natural resources and population growth degrading the environment and intensifying the competition for remaining resources. However, empirical proofs of the scarcity-conflict theory are lacking.[19] The scarcity-conflict theory has been criticized for lacking precision on the underlying causal mechanisms associating the increasing scarcity of a resource to predatory behaviors. As a result, scarcity conflicts are presented as almost instinctual responses to scarcity (Turner, 2004). In this section, we present several mechanisms linking the scarcity of pasture to the risk

[19]On a study of all sovereign States for the period 1950–2000, Urdal (2005) finds that pressure on agricultural land is not significantly associated with the risk of civil conflict. He also finds that population growth and population density do not affect the risk of civil conflict, except during the 1970s. On a study of 139 countries over the post-Cold War period, De Soysa (2002) finds that the quantity of natural resources available in a country does not have a statistically significant impact on conflict onset (unlike the availability of mineral wealth). Concerning the link between population size and conflict, his results contradict the hypothesis of a linear relationship developed in the scarcity-conflict theory. They suggest that densely populated rural societies with access to a greater wealth of renewable resources per capita tend to experience more civil conflict.

of herder-farmer conflict.

One of the leading critic made to the scarcity-conflict theory is that it neglects the adaptation capacity of individuals confronted with the scarcity of a vital resource (De Soysa, 2002; Turner et al., 2011). For individuals who can adapt, scarcity is a relative rather than an absolute issue. Relative scarcity supposes that the resource is present in some quantities, but its access carries an opportunity cost. For a typical herder, the pasture of one zone is substitutable for the ones of other zones, provided he can support the cost of moving his herd. Pasture scarcity is therefore defined in relative terms because it is associated with access to alternative grasslands. In Niger, at the end of the rainy season, pastures are scarcer, and their access becomes difficult for herders. Therefore, the opportunity cost of transhumance (i.e., the cost of reaching alternative grasslands as an adaptation strategy) diminishes: a herder will prefer a risky migration rather than an assured loss of future income (McGuirk and Nunn, 2020). Unpredictable climatic shocks such as droughts can sharply reduce the length of the rainy season and accelerate the natural depletion of pastures. They are associated with a sudden increase in the number of herders involved in transhumance, including cross-border movements (Thébaud et al., 2018; Apolloni et al., 2019). Recent empirical analyses of herder-farmer conflicts in Africa conclude that drought-induced migration of herders is associated with a higher risk of conflict (Eberle et al., 2020; McGuirk and Nunn, 2020). They suggest that competition for the remaining resources plays a significant role in the onset of herder-farmer conflicts. McGuirk and Nunn (2020) use a desegregated framework (i.e., at the level of $55x55$ kilometers grid cells at the equator) to analyze how the expansion of arid regions (proxied by precipitation measures) affects the risk of herder-farmer conflict in Africa. They show that conflicts are more likely in areas suited for both nomadic pastoralism and agriculture. They also show that drought in areas suited for nomadic pastoralism increases the risk of conflict in neighboring agricultural regions. Eberle et al. (2020) investigate the impact of climate change (proxied by temperature measures) on the risk of herder-farmer conflict in Africa. Their results also suggest that herder-farmer conflicts are more likely in cells with mixed settlements at the fringe between rangeland and farmland, especially when sudden migratory shifts destabilize traditional and mutually beneficial agreements established over the years between herders and farmers. This recent literature studies short-distance transhumance (i.e., at the scale of a cell and its direct neighbors). However, the supported mechanisms may also apply to long cross-border transhumance. By ignoring such spatial dependencies, we may underestimate the effect of climate on conflict (Maystadt and Ecker, 2014).

H1: If herder-farmer conflicts are caused by a sudden influx of nomadic herders practicing cross-border transhumance, then pasture scarcity in Niger will increase the risk of herder-farmer conflict in Nigeria.

The distance between the resources and the conflict has theoretical implications (Lujala, 2010). In Africa, institutional and academic sources report a higher risk of herder-farmer conflicts in transition zones between pasture and cropland (Olaniyan and Okeke-Uzodike, 2015; ICG, 2017). Eberle et al. (2020) and McGuirk and Nunn (2020) suggest that conflicts in transition areas are caused by competition for the remaining fertile land.

However, they do not test for grassland in the cell where the conflict appears. Conflicts in zones with pastures suggest that resource-grabbing strategies may explain herder-farmer conflicts following drought in Niger. Informal arrangements regulate the management of common resources and settle disputes over property rights (Eberle et al., 2020). Following an early depletion of pastures in Niger, the sudden increase in the flow of pastoralists moving to Nigeria may disrupt these fragile arrangements. In the absence of an institutional framework limiting issues of distribution and access to resources, the risk of violent competition for the remaining grasslands could increase (Coase, 1960; Sekeris, 2010). This channel would be magnified by grassland scarcity in Nigeria since the number of pastoralists per pasture would be higher.

H1a "Competition for the remaining resource" : If grassland scarcity causes herder-farmer conflicts through the competition channel, then conflict will be more likely in cells with pastures.

The resource-grabbing channel does not explain conflicts in pasture-less areas. **Figure 1** presents a map of the distribution of herder-farmer conflict occurrences and grasslands across the Nigerian territory between 2006 and 2016. While most conflicts appear in cells with pastures (68% of the occurrences), a large share of them appear in pasture-less cells (32%). Also, conflicts are mainly located in the middle and southern part of Nigeria, although the Northern region presents the most significant amount of pasture. The characteristics of a cell directly enter the herder's income maximization strategy, but the characteristics of neighboring cells might also influence his behavior. The value of neighboring prizes (i.e., grasslands) and the opportunity cost associated with their capture (i.e., the cost of migration) may indirectly affect the herder's decision to use violence in the cell where he is located. The expectation of high future income can act as an incentive to grab a scarce resource, but the cost of accessing the resource constrains this mechanism. Caselli et al. (2015) show that oil deposits located close to a border are more likely to be challenged by interstate conflicts because their access is less costly for both countries. Lujala (2010) shows that proximity to lootable and highly valuable resources like oil increase conflict duration independently of the quantity of resource produced. Indeed, rebel groups will finance conflict by selling in advance use rights to the oil deposits (i.e., booty futures) that they seek to grab. Depending on their spatial dispersion, accessing the remaining grasslands can be costly for herders. Since moving is expensive[20], the opportunity cost of crop encroachment (i.e., predatory behavior) decreases with the distance to the next pasture. The risk of crop encroachment is higher when herders move between pastures located far from each other. Therefore, proximity to pasture may decrease the risk of conflict in a cell. The importance of continuous access to pasture and water during long herders' movements is well known and constitute one of the primary motivation behind the implementation of transhumance corridors (Moutari and Giraut, 2013).[21] Herders and farmers generally recognize them as a factor of peace because they ensure continued access to resources and avoid the passage of animals too close to agricultural areas (Alidou, 2016). In

[20]Crossing long distances is costly for herders because it is associated with a higher risk of animal disease and death.

[21]Transhumance corridors are passage areas reserved for transhumant herds in transit between water resources, pastures, and other pastoral infrastructures like livestock markets, resting area, or vaccination zones).

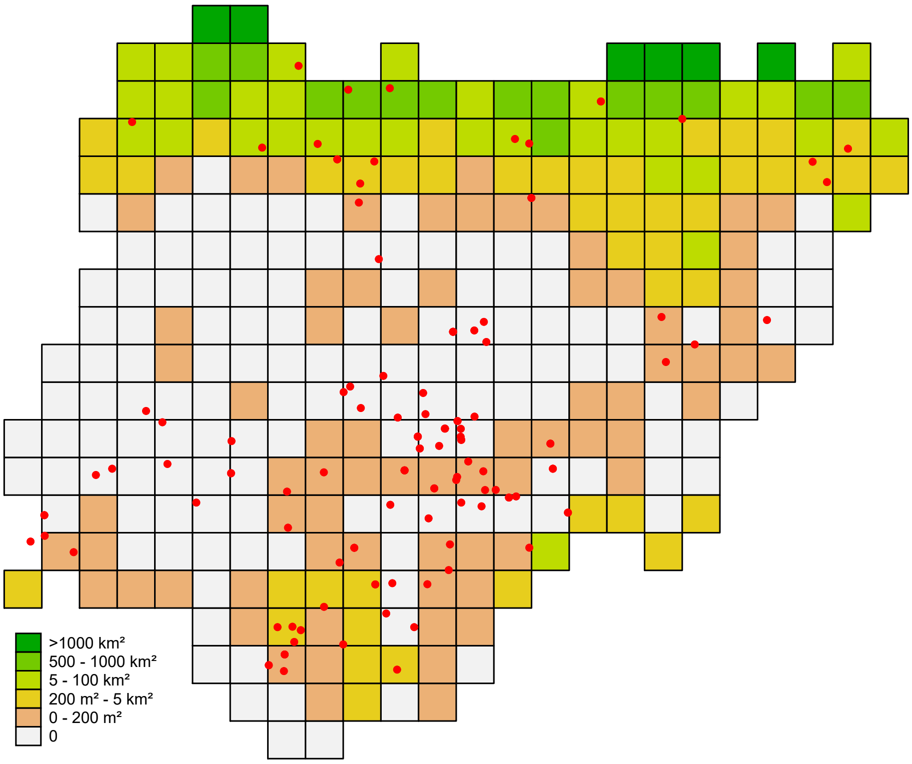
summary, the scarcity of pastures can not only cause pastoralist-farmer conflicts due to predatory behavior, but also because their access cost is higher.

H1b "Accessing the remaining resource": If grassland scarcity reduces the risk of herder-farmer conflicts by increasing the cost of accessing grazing areas in Nigeria, then conflicts will be less likely in cells close to pastures.

The farmers' decisions may also explain herder-farmer conflicts. In Nigeria, grassland scarcity is part of the broader issue of land scarcity associated with population growth and croplands' expansion (Arowolo and Deng, 2018). Grasslands represent large areas of unexploited (low quality) arable lands. Given the relative scarcity of land, farmers may consider exploiting portions of grasslands, even if this increases the probability of encountering pastoralists (Leonhardt, 2019). Nigerian farmers make a trade-off between allocating their resources to production or appropriation (i.e., grabbing the product of others or defending their production). Devoting resources to conflict is costly because it represents time and investments that they are not allocating to their agricultural production. Several studies have shown that shocks affecting agricultural incomes increase the risk of conflict by reducing the opportunity cost of conflict (see, for example Miguel et al., 2004; Hendrix and Salehyan, 2012). When farmers face droughts during the growing season of their fields, they may be more likely to engage in conflict because the return from productive activity is lower.

H2: If the farmers' opportunity cost channel causes conflicts, then adverse climatic shocks during the growing season of their cropland will increase the risk of conflict.

Finally, a possible answer to scarcity is to limit one's dependence on the diminishing supply source. In the Sahelian region, transhumance involves 70 to 90% of cattle (Kamuanga et al., 2008), and it is a fundamental aspect of the identity and climate resilience of Sahelian herders. Therefore, it is unlikely that pasture scarcity induces a drastic reduction in these activities. However, one may argue that nomadic herders can change their transhumance patterns by migrating to other Coastal countries like Ghana or Benin. This scenario is likely for Sahelian countries sharing a border with several coastal countries (Mali and Burkina Faso, for example). In the case of Niger, the majority of nomadic pastoralists are unlikely to travel to countries other than Nigeria. Indeed, Niger shares a border of 1,497 km with Nigeria and only 266 km with Benin. Also, areas dedicated to pastoralism and agro-pastoralism are primarily located near the Nigerian border, opposite to Benin.



Notes: The size of each cell is approximately 55 × 55 kilometers at the equator. Each red dot represents a dry season conflict for cattle-grazing (2006-2016). *Sources: Author's computations from Nigeria Watch database and Climate Change Initiative land cover maps.*

Figure 1: Average grassland cover and localization of conflicts between herders and farmers in Nigeria (2006-2016)

4 Data

4.1 Data Description

Herder-farmer conflict are small-scale conflicts. They involve a relatively small number of individuals and result in a relatively low number of deaths.[22] A highly-desegregated design is more appropriate for the analysis of small-scale conflicts. This analysis is based on sub-national observation units in the form of cells of 0.5 degree latitude x 0.5 degrees longitude (approximately 55 × 55 kilometers at the equator). Compared to administrative boundaries, grid-cells are exogenous to political decisions and power distribution (Michalopoulos and Papaioannou, 2013; Berman et al., 2017). Our sample contains N=305 Nigerian cells for the period 2006-2016 (T= 11 years).

The movement of transhumant pastoralists is cyclical. During the rainy season, herders from Niger and Nigeria take advantage of the rich Nigerien meadows. They gradually descend to the South at the start of the dry season and cross back the Niger-Nigeria border. **Figure 2** presents the timeline of conflicts and seasons analyzed in this article. Because we are interested in conflicts happening during the transhumance, our temporal unit of analysis is the period outside the rainy season (Herder-farmer conflicts ($year\ t$)). Climatic controls are

[22]The maximum number of casualties is 82 for our sample, with an average of 9 deaths per conflict.

measured separately for the rainy and the dry seasons.

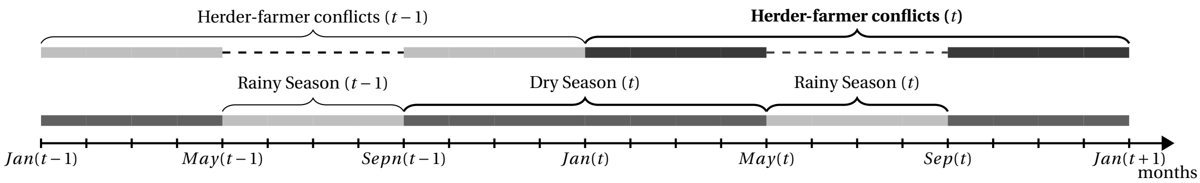


Figure 2: Timeline associated with the empirical strategy

Conflict Data - Our dependent variable comes from the Nigeria Watch database. It is the incidence of violent clashes caused by cattle grazing in Nigeria during the dry season. It is a binary indicator for whether a cell experiences at least one conflict episode in a given year's dry season. The Nigeria Watch database compiles information on homicides and violent deaths in Nigeria, including each event's date and geographic coordinates. Its sources are the Nigerian press and human right organizations reports. Because this database includes information on the cause of violent events (including cattle grazing), a precise selection of herder-farmer conflicts is possible (contrary to other violent event databases like Acled of UDCP-Prio). The Nigeria Watch database compiles information from local press and human rights organizations. One limit of this database is that it could overestimate the number of events in the regions where herder-farmer conflicts are recurrent or politicized, leading to selection bias. However, the inclusion of a rich set of fixed effects eliminates most forms of unobserved heterogeneity.

Land Cover Data - The percentage of each cell's area covered by grassland and agricultural land is compiled using remotely sensed satellite imagery of land covers from the European Space Agency (ESA) Climate Change Initiative (CCI) (ESA, 2017). These maps describe the yearly land cover at a resolution of 300 meters according to 22 classes defined by the United Nations Food and Agriculture Organization's (UN FAO) Land Cover Classification System (LCCS) (ESA). Climate Change Initiative land cover (CCI-LC) maps provide high definition information on land covers consistent over time and regions. The categories refer to different (bio)physical covers (vegetation and man-made features) and not land uses. Therefore, several types of land covers may be used for agricultural production or cattle grazing. To assess the proportion of land used as agricultural lands or grazing areas, we use the Intergovernmental Panel on Climate Change (IPCC) land classification developed by Université Catholique de Louvain (ESA). It defines six categories based on the legend used in CCI-LC maps: cropland, forest, grassland, wetland, settlement, and other lands (details on this classification are presented in **Annex A**). The CCI-2015's overall accuracy is 71% (ESA, 2017). A high level of accuracy is reported for agriculture-related land classes (>80%), but the ones associated with grasslands present lower levels of accuracy (between 34 and 42.5%). However, we use CCI-LC maps at a larger scale than the one used to assess the product's accuracy (55km instead of 300m resolution) and rely on a discrete indicator of grassland. Therefore, the accuracy of the variable indicating the presence of grassland is expected to be higher (Tsendbazar et al., 2018). Past herder-farmer conflicts could influence the size of the cell's area covered by pasture. Cases have been reported of farmers facing recurring clashes with herders that deliberately destroy or cultivate part of the nearby pastures to hinder the future passage of herds or claim high financial compensations (Dimelu et al., 2016; Leonhardt, 2019). Correlation between grassland cover and previous herder-farmer conflicts could induce an endogeneity bias. To avoid this, we use a measure of the presence of grassland (instead of the percentage of the cell covered by grassland) during the previous year. It is a dummy variable indicating if at least one pixel (300x300m) of pasture is observed in the cell during the previous year.

Climatic Data - To capture weather shocks, we use the Standardized Precipitation-Evapotranspiration Index (SPEI) developed by Vicente-Serrano et al. (2010). It is a multi-scalar drought index based on information on precipitations and the ability of the soil to retain water (which depends on latitude, sunshine exposure, temperature, and wind speed). SPEI has a mean of zero and is expressed in units of standard deviation from the cell's historical average. The conflict literature has mainly used precipitation indices to capture weather shocks affecting farmers' incomes (Miguel et al., 2004; Hendrix and Salehyan, 2012). However, the growth cycle of plants also depends on the capacity of the soil to retain water. The SPEI thus outperforms rainfall indices in predicting land yields (Vicente-Serrano et al., 2012; Harari and Ferrara, 2018). Several empirical works use shocks on the international prices of agricultural goods (Brückner and Ciccone, 2010; Dube and Vargas, 2013). This solution is not an option in our case because the pastures do not directly produce internationally valued yields, and cattle price often differs between adjacent areas since livestock markets are poorly integrated (Fafchamps and Gavian, 1997). By using the SPEI, we follow recent contributions in the conflict literature (Couttenier and Soubeyran, 2014; Harari and Ferrara, 2018).[23] The cost of transhumance depends on the distance traveled by herders. Therefore, regions located far from the Niger-Nigeria border are expected to host fewer breeders from Niger. To control for this, we also calculate for each year the average level of drought in Niger's grassland (during the rainy season) divided by the cell's distance to the Niger-Nigeria border:

$$RS - Drought\ Niger's\ grasslands\ (dist)_{k,t} = \frac{RS - Drought\ Niger's\ grasslands_t}{Distance_k}$$

Where $RS - Drought\ Niger's\ grasslands_t$ is the average drought level in Nigerien cells with pasture during the year t rainy season, and $Distance_k$ is the logarithm of the distance between the Nigerian cell k and the Niger-Nigeria border.

Other Controls - The itinerary of transhumant breeders is fluctuating and does not necessarily follow old transhumance corridors. Insecurity is one of the main reasons why pastoralists deviate from their usual itinerary (Leonhardt, 2019). Since 2009, Boko Haram has been involved in cattle rustlings, bombings, assassinations, kidnappings, and lootings in northeastern Nigeria. Using ACLED data, we control for their presence

[23] An alternative to SPEI is the Palmer Drought Severity Index (PDSI) used by Couttenier and Soubeyran (2014), but the SPEI has a higher spatial resolution (i.e., 0.5 x 0.5 degrees) which is more suitable for our empirical strategy.

using a dummy variable indicating if the cell experienced a conflict involving the group during the previous year. Overexploitation of pastures is more likely in heavily populated areas because the resource is shared among a larger number of pastoralists (Homer-Dixon, 1999). Data on population size (in logarithm) are retrieved from the Gridded Population of the World collection (CIESIN et al., 2020). The database provides cell-level information on the size of the population in 2005, 2010, 2015 and 2020 from population censuses.[24] When possible, a set of time-invariant cell-level controls is included. The transhumance paths are often close to the main roads. For each cell, we calculate the total length of roads (in kilometers) using the latest Open Street Map (OSM) data on motorways, primary, secondary, tertiary, and trunk denominations (OpenStreetMap contributors, 2017). Although the road density is usually larger in cities, herders seldom cross urban areas. We therefore exclude urban areas using GRID3 data on settlement extents (CIESIN et al., 2020)[25] Herders' movement depends on the presence of grasslands and water. We control for water resources with an indicator of the total river length per cell constructed from OSM data (OpenStreetMap contributors, 2017).

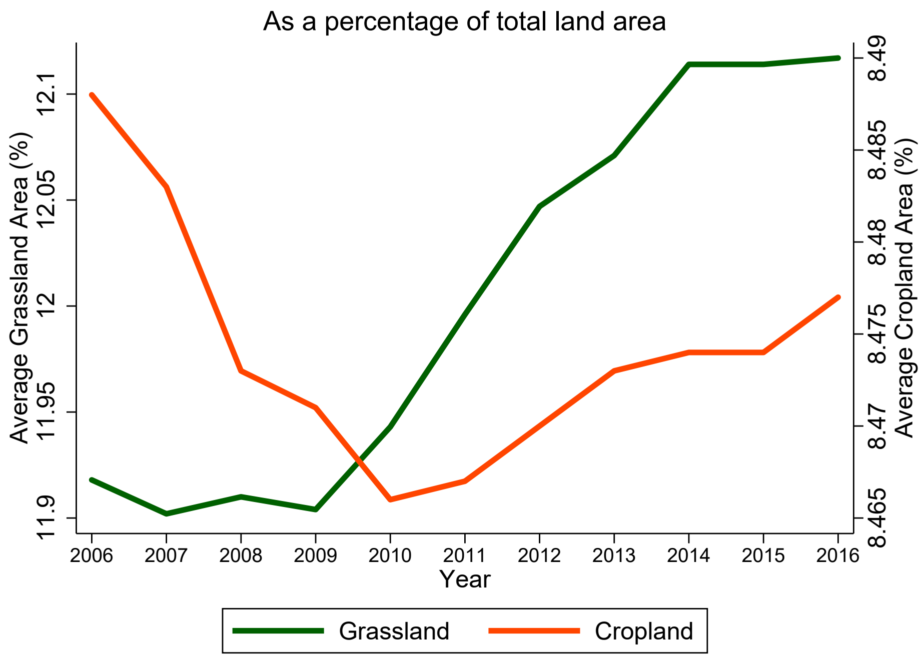
4.2 Descriptive Statistics

Annex B displays the descriptive statistics of the main variables used for the analyses. The unconditional probability of observing at least one conflict between herders and farmers in a cell is 4.3%. This level is more than twice as high during the dry season (3.1%) compared to the rainy season (1.5%). **Figure 3** presents the annual evolution of grassland and cultivated land in Niger between 2006 and 2016 (expressed as a percentage of the total area). **Figure 4** presents the annual evolution of grassland and cultivated land in Nigeria between 2006 and 2016 (expressed as a percentage of the total area). In Nigeria, the grassland cover is declining over the entire period. Grassland covers 3.48% of the territory in 2006 and 3.28% of the territory in 2016. The cropland cover increases until 2014 (from 61.21% in 2006 to 62.49% in 2014) then slightly decreases between 2015 and 2016 (from 62.47% in 2015, to 62.34% in 2016). In Niger, the grassland cover is decreasing between 2006 and 2009 but increasing between 2009 and 2014. Similarly, the cropland cover decreases until 2010 and is slightly increasing between 2010 and 2016. Between 2006 and 2016, Niger lost approximately $139 km^2$ of cultivated land and gained approximately $2,523 km^2$ of pasture. During the same period, about $10,383 km^2$ of newly cultivated land appeared in Nigeria and $1,986 km^2$ of pasture disappeared. The rise of international food prices in 2008 and the introduction of the 2010 ordinance that recognizes and protects pastoral lands may explain the sudden shift experienced by Niger between 2009 and 2010. The values observed for Nigeria are consistent with the agricultural policies and pastoralism laws that the country has implemented since its independence.

Figure 5 shows that Northern Nigeria is particularly affected by the decline in the pasture area. In the middle belt, the amount of pasture is low and stable, but there has been an expansion of the cultivated areas.

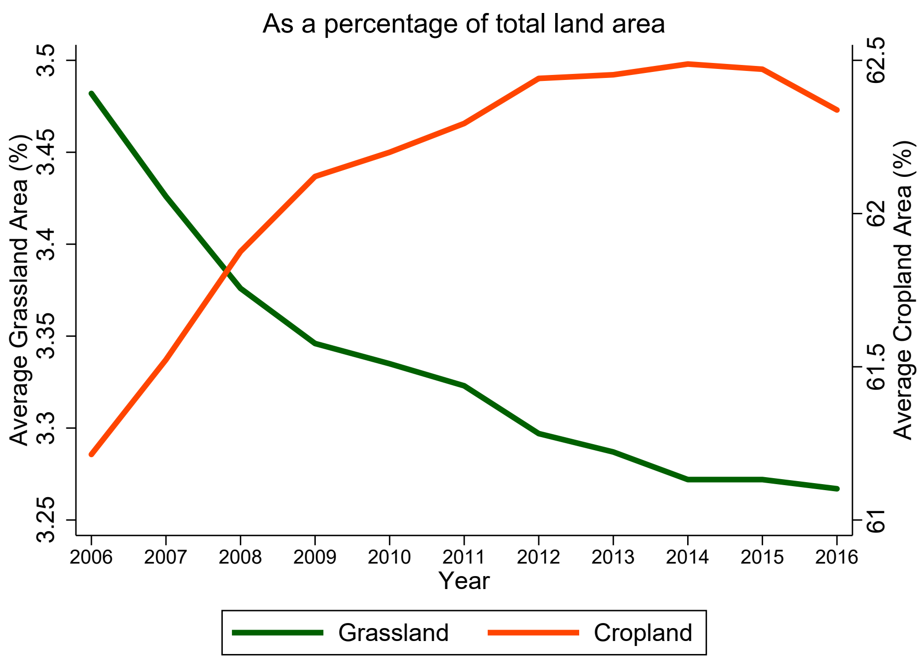
[24] Yearly data are calculated by linear interpolation.

[25] Using Qgis, we remove footprints of settlement areas and obtain a vector layer of Nigerian roads with "holes" where there is an urban center.



Notes: Values are presented as a percentage of the total land area. The left axis corresponds to grasslands, and the right axis corresponds to cultivated lands. *Source: Author's compilation.*

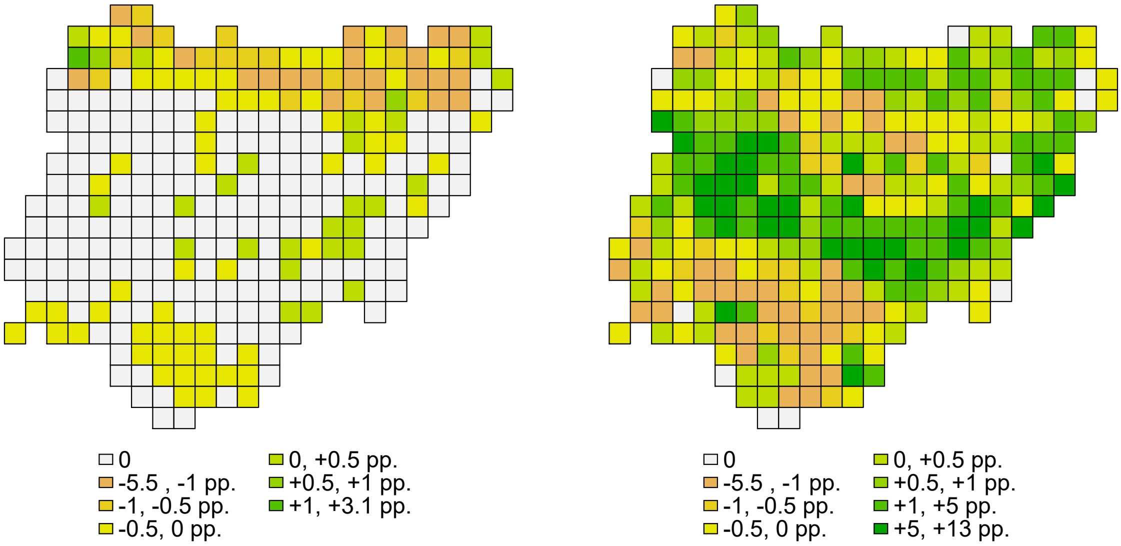
Figure 3: Annual Changes in Land Cover in Niger



Notes: Values are presented as a percentage of total land area. The left axis corresponds to grasslands and the right axis corresponds to cultivated lands. *Source: Author's compilation.*

Figure 4: Annual Changes in Land Cover in Nigeria

These changes complicate the transhumance of livestock. The decline in pastures in the North could increase the interest in moving to the South during the dry season. However, the growth in the expansion of cultivated areas and the small amount of pasture in central Nigeria makes this itinerary riskier.



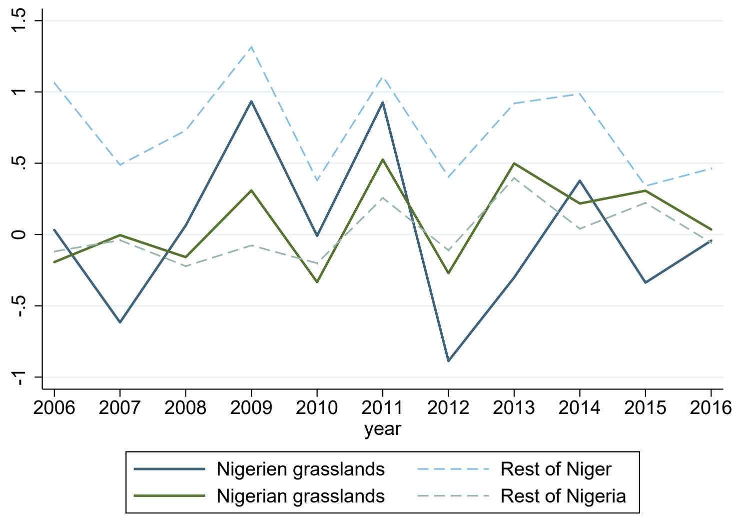
(a) Grassland Cover (b) Cropland Cover

Note: Differences between the land covers in 2016 compared to 2006 in percentage points (pp.). *Source: Author's compilation using CCI-LC maps.*

Figure 5: Changes in Grassland and Cropland Covers in Nigeria

A strong correlation between the climatic conditions in the grasslands of Niger and Nigeria could complicate our analysis by making it impossible to separate both effects. **Figure 6** presents the average value of the rainy season's SPEI in Niger and Nigeria between 2006 and 2016. It suggests that Nigerien grasslands are not always confronted with stronger droughts than Nigerian grasslands. There are as many years when drought is greater in Niger as there are years when Niger's drought is lower than in Nigeria. For each country, a distinction is made between the grassland areas (solid lines) and the rest of the territory (dotted lines). In Nigeria, grazing areas are generally exposed to drier climatic conditions than the rest of the country (except in 2006, 2010, and 2012). In Niger, grasslands are generally less dry than the rest of the territory (except in 2009 and 2011).[26]

[26] A large portion of the Nigerien territory is covered by arid deserts.



Notes: Average value of the SPEI index between June and September (rainy season). The values of the SPEI index are inverted (positive values indicate drought). Grasslands correspond to cells with a pasture cover of at least $93.3m^2$. *Source: Author's compilation.*

Figure 6: Average Value of the Rainy Season's SPEI Index (2006-2016)

5 Empirical Strategy and Methodological Challenges

5.1 Logistic Models

First, we test if the average cell-level probability of herder-farmer conflict in Nigeria is affected by sudden increases in the flow of nomadic herders following pasture scarcity in Niger (H1). If H1 holds, then an increase in the average level of pasture scarcity in Niger should be associated with a higher likelihood of herder-farmer conflict in Nigerian cells. We use logistic regression with robust standard errors. Different measures of pasture scarcity in Niger are proposed. In equation (1), the effect of pasture scarcity in Niger is measured with a variable indicating the average level of drought (SPEI index) during the previous rainy season in the Nigerien cells where there is pasture. [27] The effect of pasture scarcity in Niger is then compared with the effect of drought in the rest of the Nigerien territory (i.e., the average level of drought in the whole Nigerien territory except cells where there is grassland).

$$Y_{i,k,t} = \beta_1 D_{j,t-1} + \beta_2 X_{i,k,t} + \epsilon_{i,k,t} \quad (1)$$

Where i refers to Nigeria, and j refers to Niger. The parameters k and t denote respectively cell and year. $Y_{i,k,t}$ is a dummy variable indicating the incidence of herder-farmer conflict in the cell at a given year. $D_{j,t-1}$ is the level of drought in Niger's grasslands during the previous year's rainy season. $X_{i,k,t}$ is a vector of cell-level controls. $\epsilon_{i,k,t}$ is the error term.

[27] For purposes of clarity, the SPEI values are inverted: an increase in the index refers to an increase in drought.

In equation (2), the effect of pasture scarcity in Niger is measured with extreme values of the SPEI index (floods and droughts). A quadratic term is therefore added to equation (1).

$$Y_{i,k,t} = \quad \beta_1 D_{j,t-1} + \beta_2 D^2_{j,t-1} + \beta_3 X_{i,k,t} + \epsilon_{i,k,t} \qquad (2)$$

In equation (3), the effect of pasture scarcity is tested on different types of cells depending on their suitability for herders. Indeed, suppose pasture scarcity in Niger affects the risk of herder-farmer conflict by increasing the flow of nomad pastoralists. In that case, those effects should be observed in areas where herders are expected to be found. Three different measures are used: a dummy variable indicating grassland in the cell, an indicators of the cell's suitability for animal husbandry, and an indicators of the cell's suitability for mobile pastoralism (Beck and Sieber, 2010; McGuirk and Nunn, 2020).

$$Y_{i,k,t} = \quad \beta_1 D_{j,t-1} + \beta_2 G_{i,k,t-1} + \beta_3 D_{j,t-1} \times S_{i,k,t-1} + \beta_4 X_{i,k,t} + \epsilon_{i,k,t} \qquad (3)$$

Where i refers to Nigeria, and j refers to Niger. The parameters k and t denote respectively cell and year. $Y_{i,k,t}$ is a dummy variable indicating the incidence of herder-farmer conflict in the cell at a given year. $D_{j,t-1}$ is the level of drought in Niger's grasslands during the previous year's rainy season. $S_{i,k,t-1}$ is a variable indicating the cell's suitability for herders. $X_{i,k,t}$ is a vector of cell-level controls. $\epsilon_{i,k,t}$ is the error term.

5.2 Spatial Model

The second part of our empirical strategy integrates the spatial spillovers associated with the proximity to grasslands on the risk of herder-farmer conflict (hypotheses H1a and H1b). The introduction of control variables considering the characteristics of neighboring cells can only partially resolve spatial autocorrelation issues. Indeed, such models would neglect the effect of conflicts in a neighboring cell j on the risk of conflict in cell i. Herder-farmer conflicts might be spatially autocorrelated. For discrete variables, the recommended local indicator of spatial association is the join count statistic (Cliff and Ord, 1973). In this case, spatial correlation manifests in the form of a pattern in which neighboring cells are more likely to display the same value "1" (or opposite value "0") than would be expected in the absence of spatial autocorrelation. The join count test consists in classifying the joins between contiguous cells as either "1:1", "0:0", or "1:0". The frequencies of the joins are then compared to the expected frequencies under the null hypothesis of spatial randomness (Cliff and Ord, 1981).

Table 1 reports the results of the join count analysis when neighbors are defined according to a first-order row-standardized Queen contiguity spatial weight matrix. They show that herder-farmer conflicts exhibit spatial dependence in three out of eleven years examined. In 2011, 2013 and 2016, contiguous cells exhibit positive spatial dependence in conflicts ($(1:1)$ joins in the table). For each of these years the observed $(1:1)$ join counts were at least twice as large as what we would expect to observe under the null hypothesis of spatial randomness (which is rejected at the 99% level). A positive spatial dependence in conflicts is also supported by the

(1:0) joins, which reflect instances in which a cell not experiencing a herder-farmer conflict is contiguous to a cell in conflict. In 2013 and 2016, the (1:0) joins are less common than what would be expected under spatial randomness. It suggests that peaceful cells close to cells in conflict are less common than we would expect if spatial location were irrelevant for herder-farmer conflict. In 2013 and 2016, a cell without herder-farmer conflicts is likely surrounded by a cell without conflict. For these years, the observed join counts are slightly but significantly larger than what we would expect to observe under the null hypothesis of spatial randomness at least at the 90% level. In short, in 2013 and 2016, cells experiencing conflict are likely surrounded by cells in conflict, and cells in peace by cells in peace. It suggests that herder-farmer conflicts may be distributed in a non-uniform way in Nigeria.

Table 1: Join Count Results for Herder-Farmer Conflicts in Nigeria (2006-2016)

Year	Number of Conflicts	Join Type	Count	Permutation Mean	Variance	Z-Stat
2006	0			Not Applicable		
2007	6	0:0	146.52	146.55	0.04	-0.147
		1:1	0.00	0.05	0.01	-0.598
		1:0	5.98	5.90	0.06	0.322
2008	7	0:0	145.21	145.57	0.05	-1.609
		1:1	0.00	0.07	0.01	-0.710
		1:0	7.29	6.86	0.08	1.545
2009	6	0:0	146.65	146.55	0.04	0.488
		1:1	0.00	0.05	0.01	-0.598
		1:0	5.85	5.90	0.06	-0.202
2010	5	0:0	147.47	147.53	0.03	-0.343
		1:1	0.00	0.03	0.00	-0.487
		1:0	5.03	4.93	0.05	0.444
2011	3	0:0	149.62	149.51	0.02	0.835
		1:1	0.13***	0.01	0.00	3.092
		1:0	2.75	2.98	0.02	-1.521
2012	10	0:0	142.57	142.65	0.07	-0.283
		1:1	0.38	0.15	0.02	1.610
		1:0	9.55	9.70	0.13	-0.414
2013	23	0:0	131.78***	130.33	0.21	3.143
		1:1	1.75***	0.83	0.10	2.866
		1:0	18.97***	21.34	0.50	-3.340
2014	13	0:0	140.14	139.76	0.10	1.202
		1:1	0.38	0.26	0.03	0.644
		1:0	11.98	12.49	0.20	-1.131
2015	10	0:0	142.25	142.65	0.07	-1.440
		1:1	0.13	0.15	0.02	-0.163
		1:0	10.12	9.70	0.13	1.151
2016	21	0:0	132.96*	132.19	0.19	1.784
		1:1	1.64***	0.69	0.09	3.241
		1:0	17.89***	19.62	0.43	-2.627

Notes: * p<0.1, ** p<0.05, *** p<0.001. The spatial weight matrix in a first-order row-standardized Queen contiguity matrix. Results were obtained using the *joincount.multi* command on R. Column "Number of Conflicts" presents the number of cells experiencing at least one herder-farmer conflict during the considered year. *Source: Author's compilation.*

Join count statistics must be interpreted with caution in case of rare event and large data set (Anselin and Li, 2019). As Anselin and Li (2019) note, "*any occurrence of a rare event surrounded by another event is likely to be so* *exceptional that it automatically becomes significant.*" Between 2007 and 2011, not many conflicts are reported and (1 : 1) joins are never observed (i.e., $Count = 0$ in the table). In 2011, the number of conflict event is low (i.e., each cell has 0.98% chance to experience conflict) but the join count test supports the presence of positive spatial autocorrelation at the 99% level. These observations suggest that 1:1 joins are very rare in our sample before 2011 and probably because not many events are reported. In view of the results and the limitations of the join count tests, the presence of positive spatial autocorrelation is likely enough (at least, for certain years) that this issue cannot be overlooked.

To complete this exploratory analysis, we look at the spatial pattern of the average incidence of herder-farmer conflict per cell for the whole period (2006-2016). This variable is continuous with values in the range from 0 to 1. Higher values indicate a higher average risk of conflict in the cell during the period. The Moran's I statistic is the most common indicator of global spatial correlation for continuous variables (Le Gallo, 2002). **Annex C** presents the Moran's I statistic and scatter plot associated with the cells' average incidence of herder-farmer conflict between 2006 and 2016, using a first-order row-standardized Queen contiguity weight matrix.[28] The Moran's I statistic is positive with a value of 0.257 and significant at the 0.001 level.[29] This result confirms that the average incidence of conflict between herders and farmers is spatially autocorrelated. **Annex D** presents the cluster map associated with the Moran's I statistic. It shows the type of spatial association for cells with a significant (p<0.05) local Moran's I statistic. This map indicates that the global spatial auto-correlation is primarily influenced by the Middle Belt states (particularly Benue, and Nasarawa) and in southeastern Nigeria (particularly in Enugu and Anambra States). In these regions, cells with an average conflict incidence higher than the sample's mean are surrounded by similar cells.

The selection of the most suitable spatial model follows the specific-to-general procedure (Elhorst, 2010). It consists in starting from an spatial Durbin model (SDM) and test the validity of alternative specifications. Using matrix notation, the SDM model takes the form:

$$Y = \rho WY + \beta X + \theta WX + \epsilon \qquad (4)$$

In equation (4), if $\theta = 0$ and $\rho \neq 0$, then the most appropriate model is a spatial autoregressive model (SAR). If $\theta = -\beta\rho$ in equation (4), then the most appropriate model is a spatial error model (SEM). Following Belotti et al. (2017), we test these linear and non-linear hypotheses. The tests successively reject the null hypotheses (i) $H0 : \theta = 0$, and (ii) $H0 : \theta = -\beta\rho$ with a risk of error of the first kind of 0.03%. Then, we test if the spatial autocorrelation model (SAC) is more appropriate than the SDM. Because the SAC and the SDM are nonnested, we compare the Akaike information criterion (AIC) associated with both models. With an AIC of −2910.116 for the SDM model and an AIC of −2883.416 for the SAC model, the SDM model is preferred. We estimate the

[28] Row-standardization takes the binary zero-one weights and divides them by the row sum.

[29] The significance of the Morans'I index is estimated by assuming normality (*moran.test* command on R) and through a Monte Carlo procedure using 999 permutations (*moran.mc* command on R). The similarity of the results ensures the robustness of our conclusions regarding the spatial autocorrelation (Ardilly et al., 2018).

following spatial Durbin model on a balanced panel through quasi-maximum likelihood:[30]

$$\begin{aligned} Y_{i,k,t} = \quad & \alpha_{ikt} + \rho W Y_{i,k,t} + \beta_2 G_{i,k,t-1} + \beta_3 D_{j,t-1} + \beta_4 (G_{i,k,t-1} \times D_{j,t-1}) + \beta_5 W G_{i,k,t-1} + \beta_6 W D_{j,t-1} + \\ & \beta_7 W (G_{i,k,t-1} \times D_{j,t-1}) + \beta_8 X_{i,k,t} + \beta_9 W X_{i,k,t} + FE_{i,k} + FE_{i,t} + \epsilon_{i,k,t} \end{aligned} \quad (5)$$

Where i refers to Nigeria, j refers to Niger. The parameters k and t denote respectively cell and year. $Y_{i,k,t}$ is a dummy variable indicating the incidence of herder-farmer conflict in the cell at a given year. W is a row-standardized Queen contiguity matrix. $D_{j,t-1}$ is the level of drought in Niger's grasslands during the previous year's rainy season. $G_{i,k,t-1}$ is a dummy variable indicating grassland in the cell last year.$X_{i,k,t}$ is a vector of controls. $FE_{i,t}$ are time fixed effects, $FE_{i,k}$ are cell fixed effects, α_{ikt} is the constant, and $\epsilon_{i,k,t}$ is the error term.

One classical question in spatial panel data empirical analyses is the choice between spatial random effects and spatial fixed effects. This issue is addressed by using the robust Hausman test (Belotti et al., 2017). The results (reported at the bottom of **Table 5**) indicate that the spatial random effects estimator is outperformed by the spatial fixed effects estimator (the null hypothesis is rejected with a χ^2 test statistic of 44.86 and a p-value inferior to 1%). Year and cell fixed effects are introduced to the model to control for a large number of omitted variables. Year fixed effects remove cyclical variations that concern each cell equally, such as international price variations, changes in total area of pasture in Niger and Nigeria, or regime changes. Cell fixed effects control for any characteristic that differs between cells while being constant over time. Such confounders include the geographical distribution of religious or ethnic groups within Nigeria, geographic characteristics (for example, rivers, mines, or urban centers), and systematic coverage bias of the dependent variable.

The spatial Durbin model reduces the endogeneity bias from omitted variables that are spatially correlated (Fingleton and Le Gallo, 2010). For example, we might suspect the dummy variable indicating pasture to only partially remove the reverse causality issue between pasture and conflict. Some regions are more hostile than others to open-grazing and transhumance. In these areas, farmers may fully destroy remaining pastures (i.e., variation from 1 to 0 of the dummy variable).[31] This hostility is complex to integrate in an empirical analysis. It is linked to the political, ethnic and religious issues of certain regions and is maintained in the speeches of federal governments and interest groups (Chukwuma, 2020). The omission of local hostility towards pastoralism could be a source of endogeneity. As this variable is linked to political, ethnic and religious issues, it is likely spatially correlated (i.e., hostile cells are most likely located near cells where pastoralism is linked to similar issues). When the omitted variable is spatially correlated, LeSage and Pace (2008) and Pace and LeSage (2008) show that its effect is eliminated by the SDM, which provides unbiased estimates of the coefficient associated to the endogenous variable.

In a second spatial model, we test the validity of Hypothesis 2 related to the farmers' strategy. We isolate the effects of their agricultural yields and opportunity costs by focusing on weather shocks during the growing

[30]We use the Stata command *xsmle* developed by Belotti et al. (2017). Several articles where the dependent variable is a binary measure of the incidence of conflict use this quasi-maximum likelihood technique (See, for example, Ralston, 2013; Harari and Ferrara, 2018).

[31]Nevertheless, variations of the dummy variable are seldom observed in the sample.

season (Harari and Ferrara, 2018). We use data on the main crop's growing season start and end months developed by (Portmann et al., 2010) and match these crop calendars with the relevant SPEI data for each cell.[32] Three variables are added to **Equation (5)**: the level of drought during the cell's main crop growing season, the proportion of the cell covered by crops, and an interaction term of both variables.[33]

6 Results

6.1 Average Effect of Grassland Scarcity in Niger on Herder-Farmer Conflicts in Nigeria

Table 2 presents the results of the logistic model. Contrary to our expectations, dryer rainy seasons in Niger are associated with a significantly lower risk of conflict in Nigeria. Column (1) shows that a one-standard-deviation increase in the drought index of Niger's grasslands during the rainy season decreases by 0.6 percentage points the risk of herder-farmer conflict in Nigeria during the next dry season (holding all the control variables at their mean). Instead of analyzing drought, we now analyze the effect of extreme climatic events (floods and droughts) on the risk of herder-farmer conflict. In column (2), a quadratic measure of the variable of interest is added to the model. The sign of the coefficient associated with the log measure is unchanged and stays strongly significant (p<0.001). The coefficient associated with the quadratic measure is significant (p<0.01) and positive. It suggests a U-shaped link between the dryness in Niger's grasslands and the risk of herder-farmer conflict in Nigeria. **Annex E** presents a plot of the average predicted probability of herder-farmer conflict depending on the level of drought in Niger's grasslands. The lowest probability of conflict is observed for an approximate 0.4 deviation relative to the average level of the drought, holding other controls at their mean. The risk of herder-farmer conflict increases with deviations superior to this level. The confidence intervals associated with extreme drought index values (either very low or very high) are larger, suggesting possible heterogeneous effects across Nigeria.

Columns (3) and (4) show that there is a significant linear link (p<0.001) between droughts in the rest of Niger's territory (i.e., excluding grasslands) and the risk of herder-farmer conflict in Nigeria, but no proof of a curvilinear relationship is found. Finally, column (5) presents the results when cell fixed effects are added to the model. The curvilinear effect of the rainy season's drought in Niger's grasslands stays significant with only marginal changes to the coefficients.

In all specifications, the climatic conditions in Nigeria are positively but not significantly associated with the risk of herder-farmer conflict. The coefficient associated with the SPEI of the dry season in the cell is never significant. The one associated with the SPEI of the previous rainy season is weakly significant ($p < 0.05$), but it becomes insignificant when cell fixed effects are added to the model. The distance to the border and the road's length significantly increase the risk of herder-farmer conflict. Holding all the control variables at their mean

[32] For example, we use the SPEI05 calculated in October for cells where the growing season starts in June and ends in October (i.e., the growing season lasts five months).

[33] The control variable indicating the level of drought during the dry season is removed because it is correlated with the variable indicating the level of drought during the growing season.

in our baseline specification (column 1), a one-standard-deviation increase in distance to the border and the road's length are respectively associated with a 0.8% and a 1.2% increase in the likelihood that a pastoralist-farmer conflict arises in Nigeria during the next dry season (holding all the control variables at their mean). The amount of freshwater is negatively associated with the risk of herder-farmer conflict. A one-standard-deviation increase in the river's length decreases the risk of conflict by 1.2% (holding all the control variables at their mean). A larger population size significantly ($p<0.001$) increases the risk of herder-farmer conflict, even when the model includes cell-fixed effects. Holding all the control variables at their mean in our baseline specification (column 1), a one-standard-deviation increase in population size is associated with a 0.6% increase in the likelihood of herder-farmer conflict (holding all the control variables at their mean). Finally, we find no evidence that Boko Haram activity significantly influences the risk of herder-farmer conflict in the cells.

Table 2: Table of Results - Logistic Model (Drought in Niger)

	(1)	(2)	(3)	(4)	(5)
L.RS-Drought Niger (grassland)	-0.650**	-0.678***			-0.608**
	(0.236)	(0.183)			(0.187)
L.RS-Drought Niger (grassland) sq		0.835**			0.874**
		(0.292)			(0.317)
L.RS-Drought Niger (no grassland)			-1.232***	-1.163***	
			(0.338)	(0.353)	
L.RS-Drought Niger (no grassland) sq				0.686	
				(1.412)	
Border Distance	0.523***	0.522***	0.512***	0.510**	
	(0.154)	(0.155)	(0.155)	(0.155)	
L.RS-Drought	0.317*	0.333*	0.388*	0.385*	0.134
	(0.146)	(0.140)	(0.153)	(0.153)	(0.171)
DS-Drought	0.111	0.124	0.156	0.161	0.082
	(0.126)	(0.134)	(0.111)	(0.110)	(0.146)
Population	0.408***	0.406***	0.401**	0.400**	6.632***
	(0.121)	(0.123)	(0.122)	(0.123)	(1.417)
Roads Length	0.647***	0.652***	0.661***	0.663***	
	(0.154)	(0.156)	(0.158)	(0.158)	
River Length	-3.527***	-3.556***	-3.578***	-3.575***	
	(0.815)	(0.819)	(0.826)	(0.825)	
L.Boko Haram Activity	0.046	0.041	0.048	0.048	-0.017
	(0.030)	(0.029)	(0.029)	(0.029)	(0.031)
Log-lik	-412.37	-408.48	-410.41	-410.30	-186.56
Obs	3355	3355	3355	3355	726
Cell F.E.	No	No	No	No	Yes

Notes: * p<0.05, ** p<0.01, *** p<0.001. Results were estimated using logistic regressions. The coefficients are log odds-ratios. Robust standard errors are in parentheses. The outcome variable is a dummy variable indicating the incidence of conflict between herders and farmers during the dry season, according to the Nigeria watch database. It takes the value "1" if there is at least one conflict episode in the cell during the year considered. *Source: Author's compilation.*

The hypothesis that climate-induced flows of nomadic herders increase the risk of herder-farmer conflict suggests that the likelihood of conflict is higher in places where they move. We now test if the effect of drought in Niger's pasture depends on the cell's suitability for herders. **Table 3** presents the results of the logistic regression that includes an interaction between the level of drought in Niger's grassland and different measures of the cell's suitability for nomadic pastoral activity. Each variable is presented in its standard and mean-centered version. "L.RS-Drought Niger (g)" indicates the effect of an increase of the drought measure in Niger's grasslands when the suitability measure is maintained at zero or its mean value (for mean-centered variables). The coefficient associated with the suitability measure indicates the effect of their increase under normal climatic conditions. The interaction term indicates if the marginal effect of drought in Niger's grassland is a linear function of the suitability measure. The results indicate that the effect of Niger's grasslands drought is not higher in areas where herders should be found. On the contrary, the significant and negative coefficients associated with "L.RS-Drought Niger (g)" suggest that Niger's drought predominantly reduce the likelihood of conflict in less attractive areas for herders: areas with no pasture, low or average suitability for mobile pastoralism and animal husbandry, or average river length. An increase in the suitability of an area for herders is positively but not significantly associated with the risk of herder-farmer conflict. In **Annex H**, we add a third term to the interaction (i.e., a quadratic form) to test if the effect of Niger's drought is non-linear. No proof of a quadratic relation is found and the results remain unchanged.

Table 3: Table of Results - Logistic Model (Nomadic Pastoralism suitability)

	(1)	(2)	(3)	(4)	(5)
L.RS-Drought Niger (g)	-1.278*	-1.230*	-0.678**	-0.734*	-0.626**
	(0.498)	(0.517)	(0.237)	(0.295)	(0.243)
L.Grassland	0.505				
	(0.275)				
L.Grassland × L.RS-Drought Niger (g)	0.859				
	(0.567)				
Mobile Pastoralism Suit.		1.356			
		(0.728)			
L.RS-Drought Niger (g) × Mobile Pastoralism Suit.		2.028			
		(1.612)			
Mobile Pastoralism Suit. (c)			1.356		
			(0.728)		
L.RS-Drought Niger (g) × Mobile Pastoralism Suit. (c)			2.028		
			(1.612)		
Animal Husbandry Suit.				-0.898	
				(2.370)	
L.RS-Drought Niger (g) × Animal Husbandry Suit.				2.154	
				(4.856)	
Animal Husbandry Suit. (c)					-0.898
					(2.370)
L.RS-Drought Niger (g) × Animal Husbandry Suit. (c)					2.154
					(4.856)
Log-lik	-409.51	-409.79	-409.79	-412.09	-412.09
Obs	3355	3355	3355	3355	3355
Controls	Yes	Yes	Yes	Yes	Yes

Notes: * p<0.05, ** p<0.01, *** p<0.001. Results were estimated using logistic regression. The coefficients are log odds-ratios. Robust standard errors are in parentheses. The outcome variable is a dummy variable indicating the incidence of conflict between herders and farmers during the dry season, according to the Nigeria watch database. It takes the value "1" if there is at least one conflict episode in the cell during the year considered. "L.RS-Drought Niger (g)" is the level of drought in Niger's grassland during the previous rainy season (Vicente-Serrano et al., 2010). (c) indicates a mean-centered variable. Indicators of the cell's suitability (Suit.) for animal husbandry and mobile pastoralism come from Beck and Sieber (2010). Controls include the level of drought during the previous rainy season and during the dry season, Boko Haram activity during the previous year (dummy variable), population size, road length, river's length, and distance to the Niger-Nigeria border. *Source: Author's compilation.*

According to these preliminary results, drought episodes specifically affecting the pastures of Niger do not show the expected effect. Dryer conditions in Niger's pasture generally reduce the risk of herder-farmer conflict in Nigeria. We find evidence that extreme climatic events in Niger's grassland (droughts and floods) can increase the risk of conflict, but their effect appears relatively small and heterogeneous. Also, the climatic conditions in Niger's grasslands affect areas where there are seldom nomadic herders. This finding is hardly compatible with the hypothesis that sudden shifts in migratory flows of pastoralists from Niger increase the risk of herder-farmer conflict in Nigeria. We reject the hypothesis that stronger flows of pastoralists from Niger increase the average risk of herder-farmer conflict at the level of the whole Nigerian territory. However, this does not mean that climate-induced flows of pastoralist do not locally increase the risk of conflict.

6.2 Spatial Effects of Pasture Scarcity on the Risk of Herder-Farmer Conflict

This section explores the local effect of drought in Niger's grassland (i.e., pasture scarcity in Niger) on the risk of herder-farmer conflict, taking into account spatial spillovers. **Table 4** presents the results of the spatial Durbin models depending on the types of fixed effects included: cell fixed effects (column 1), time fixed effects (column 2), or both (column 3). The objective here is to test how the spatial distribution of grasslands affects the risk of conflict between nomadic herders from Niger and Nigerian farmers. The variables of interest are "L.Grass x L.RS-Drought Niger's grasslands (dist)" and spatially lagged counterpart "W x (L.Grass x L.RS-Drought Niger's grasslands (dist))."

For all specifications, the characteristics of the studied cell have low predictive power. In pasture-less cells, the effect of drought in Niger's pastures has the expected negative sign but is not significant. Likewise, under normal climatic conditions in Niger's pastures, pasture in the cell has a positive but insignificant effect on the risk of herder-farmer conflict. In columns (1) and (2), the coefficient associated with the variable of interest is significant ($p<0.05$), positive, and presents a similar magnitude of 0.182 in both columns. However, when country and year fixed effects are added (column 3), this effect is no longer significant at the 5% level ($p = 0.051$).

Many direct and spatial effects are acting in opposite directions. The results presented in columns (1) to (3) suggest that the risk of herder-farmer conflict in a cell strongly depends on the characteristics of the cells surrounding it. The coefficient on the spatially lagged variable of interest is negative and significant ($p<0.05$ in columns (1) and (2), and $p<0.01$ in column (3)). In cells surrounded by no pasture, dryer conditions in Niger's pastures have a positive but not significant effect on the risk of herder-farmer conflict. Under normal climatic conditions in Niger's pastures, pasture in the neighborhood increases the risk of herder-farmer conflict. This coefficient is only significant ($p<0.01$) in models taking into account cell fixed effects. When the model only includes year fixed effects (column 2), the coefficient's magnitude approaches zero and is not significant anymore at the 5% level. It suggests that it is not the absence but disappearance (presence but apparition) of grasslands in the neighborhood that reduces (increases) the risk of herder-farmer conflict under normal climatic conditions in Niger. Under normal climatic conditions in Niger's grasslands, the flow of herders from Niger is supposedly maintained at its average value. Therefore, this effect is not linked to a sudden increase in the flow of nomadic pastoralists. It could be associated with small-scale transhumance practiced by local Nigerian herders. We note that yearly changes in the dummy variables indicating the presence of grassland are uncommon and concern 0.5% of the observations.

The coefficient ρ associated with the spatial autoregressive term $W \times Y$ indicates how conflicts in the neighborhood affect the risk of conflict in the cell. It is positive and significant regardless of the type of fixed-effect used. Column (3) reports that conflict in one of the neighboring cells induces an 8.1 percentage point increase in the probability of herder-farmer conflict in the cell. It suggests that conflicts in the neighborhood increase the risk of conflict in the cell for reasons other than pastures and climatic conditions (in Nigeria and Niger). When we do not consider cell fixed effects (column 2), the coefficient rho's magnitude doubles and becomes significant at the 0.1% level, suggesting that time invariant cells' characteristics largely influence the spatial autocorrelation. In column (3), the low level of significance of ρ shows that spatial autocorelation is partially mitigated by the inclusion of cell fixed effects. Nonetheless the null hypothesis of absence of spatial autocorrelation can only be rejected completely with a spatial autoregressive term. This result is consistent with the observations of several reports and articles showing that there is a geographic clustering of herder-farmer conflicts in some regions of Nigeria (Leonhardt, 2019; Madu and Nwankwo, 2020).

Table 4: Table of Results - Spatial Durbin Model

	(1)	(2)	(3)
L.Grass	0.022	0.006	0.024
	(0.027)	(0.010)	(0.026)
L.RS-Drought Niger's grasslands (dist)	-0.105	-0.255	-0.264
	(0.291)	(0.298)	(0.297)
L.Grass x L.RS-Drought Niger's grasslands (dist)	0.182*	0.182*	0.173
	(0.089)	(0.089)	(0.089)
L.RS-Drought	-0.059	-0.058	-0.068
	(0.035)	(0.039)	(0.037)
DS-Drought	0.082*	0.049	0.065*
	(0.032)	(0.031)	(0.033)
L.Boko Haram Activity	0.001	0.003**	0.001*
	(0.001)	(0.001)	(0.000)
Population	-0.196	0.012	-0.064
	(0.169)	(0.008)	(0.174)
L.Grass	0.267**	0.002	0.276**
	(0.085)	(0.013)	(0.085)
L.RS-Drought Niger's grasslands (dist)	0.040	0.647	0.697
	(0.289)	(0.449)	(0.449)
L.Grass x L.RS-Drought Niger's grasslands (dist)	-0.234*	-0.315*	-0.335**
	(0.110)	(0.124)	(0.125)
L.RS-Drought	0.065	0.064	0.078*
	(0.037)	(0.043)	(0.039)
DS-Drought	-0.084*	-0.036	-0.056
	(0.033)	(0.033)	(0.035)
L.Boko Haram Activity	-0.009**	-0.009***	-0.008**
	(0.003)	(0.002)	(0.003)
Population	0.341	0.004	-0.301
	(0.182)	(0.010)	(0.509)
ρ	0.106*	0.167***	0.081*
	(0.042)	(0.045)	(0.041)
Log-lik	1458.05	1201.13	1471.06
Obs	3355	3355	3355
Hausman χ^2	44.14	21.78	44.86
Hausman p-value	0.00	0.11	0.00
Cell fixed effects	Yes	No	Yes
Time fixed effects	No	Yes	Yes

Notes: * p<0.05, ** p<0.01, *** p<0.001. Results were estimated using a fixed-effects spatial Durbin model. Robust standard errors are in parentheses. The outcome variable is a dummy variable indicating the incidence of herder-farmer conflict during the dry season, according to the Nigeria Watch database. It takes the value "1" if there is at least one conflict episode in the cell during the year considered. *Source: Author's compilation.*

It is impossible to directly interpret the coefficient presented in table 4 because they ignore the spatial autoregressive effects (Ardilly et al., 2018). Scalar summary measures are used to average these impacts. The average[34] direct effect indicates the impact on the risk of herder-farmer conflict in the cell i of the ith observation of the variable. It considers feedback effects that arise from the change in the variable on the risk of conflict in neighboring cells. The average indirect effect measures the average effect on the risk of herder-farmer conflict in a cell of a change in the variable in all neighboring cells. Finally, the average total effect is the combination of the average direct effect and the average indirect effect.

Table 5 presents the average total, direct and indirect effects of the interest variables. Column (1) presents the equilibrium effects associated with the baseline SDM specification. The magnitude and significance of the variables' direct and indirect effects are relatively similar to those of the coefficients presented in **Table 4**. The direct effect of the regressor of interest (the interaction term between grassland and the dryness of Niger's grasslands) is now significant at the 5% level. A one unit increase in the level of drought in Niger's grasslands increases on average by 17.8 percentage points the likelihood of herder-farmer conflict in cells with grassland. Under average climatic conditions in Niger's grasslands, grassland in the cell has no significant impact on the likelihood of herder-farmer conflict. Therefore, these results go in the direction of a reduction in the opportunity cost of conflict when pastoralists face pasture scarcity in Niger.

Pastures in neighboring cells have a large and significant indirect effect on the risk of herder-farmer conflict. If all neighboring cells provide grassland under normal climatic conditions in Niger's grasslands, then the risk of herder-farmer conflict in the cell significantly ($p<0.001$) increases by 29.9 percentage points. However, if all neighboring cells provide grassland, a one unit increase in the level of drought in Niger's grasslands significantly ($p<0.01$) decreases the risk of herder-farmer conflict by 35.6 percentage points. The direct and indirect effects of the interaction term cancel each other out, leaving a negative and not significant total effect. The total effect of the presence of grassland following normal climatic conditions in Niger's grasslands is positive and highly significant ($p<0.001$). If all cells provide grazing areas, the risk of herder-farmer clash increases by 32.7 percentage points in a typical cell.

We note that the climatic conditions in Nigeria do not have a significant total effect on the risk of herder-farmer conflict. On the one hand, the level of drought during the dry season has a significant ($p<0.05$) and positive direct effect, but an insignificant total effect. On the other hand, the level of drought during the previous rainy season has a significant ($p<0.05$) and positive indirect effect but an insignificant total effect. Proximity to areas where Boko Haram is active significantly reduces the risk of herder-farmer conflict. A previous occurrence of conflict involving Boko Haram in each neighboring cell induces a 0.9 percentage point decrease in the probability of herder-farmer conflict in the cell.

Column (2) presents the second spatial model specification (i.e., when the interests of Nigerian farmers are taken into account). We expect farmers who experienced drought during the growing season of their crop to face a lower opportunity cost of violence. The obtained results do not support this hypothesis. Although the coefficients associated with the interaction term are positive, they are never significant. Moreover, the size of

[34] Averaged over all n cells.

the crop and the level of drought during the growing season have no significant direct, indirect, or total effects.

Several implications can be drawn from the results of the spatial models. First, we find evidence that proximity to grassland reduces the risk of conflict between nomadic herders from Niger and farmers from Nigeria.[35] Indeed, the negative and significant effect associated with the spatially lagged interaction term (between a previous drought in Niger's grasslands and Nigerian cells with pastures) shows that the dryer the conditions in Niger's pasture, the more proximity to grassland reduces the risk of herder-farmer conflict. This result suggests that pastures in Nigeria are important for herders using cross-border transhumance as a coping mechanism. However, we found that this effect is more linked to dryer climatic conditions in Niger's grasslands than actual grassland scarcity. Indeed, the interaction between the squared value of drought in Niger's grassland and the presence of grassland in the cell is not significant. Herders might undertake a cross-border transhumance before facing absolute grassland scarcity.

Secondly, we find small and inconsistent evidence of scarcity-induced predatory behaviors of nomadic herders from Niger in Nigerian cells. It suggests that the appropriation of the remaining pastures is generally not the primary motivation behind herder-farmer conflicts.

Thirdly, the opening of new grazing areas is associated with a higher risk of herder-farmer conflict in Nigeria under normal climatic conditions in Niger's grasslands. The implications of this result are beyond the scope of this article because they are likely influenced by local herders practicing short-distance transhumance. It indicates that herders are more likely to enter into conflict with farmers in areas close to pastures under normal climatic conditions in Niger.

Finally, we find evidence that dryer climatic conditions during the dry season in the cell and previous droughts in neighboring cells increase the risk of herder-farmer conflict during the dry season. These results are in line with the ones of Eberle et al. (2020); McGuirk and Nunn (2020). Dryer rainy seasons push pastoralists to graze their herd in nearby areas, causing conflicts with local farmers.

[35] It is important to note that "herders from Niger" refer to nomadic herders practicing seasonal migration from Niger to Nigeria during the dry season, not herders with the Nigerien nationality.

Table 5: Total, Direct and Indirect Effects - Spatial Durbin Model

	(1)	(2)
DIRECT		
L.Grass	0.028	0.029
	(0.027)	(0.026)
L.RS-Drought Niger's grasslands (dist)	-0.267	-0.247
	(0.283)	(0.280)
L.Grass × L.RS-Drought Niger's grasslands (dist)	**0.178***	**0.175***
	(0.085)	(0.084)
L. Crop size		-0.491
		(0.346)
GS-Drought		0.025
		(0.020)
L.Crop size × GS-Drought		**0.012**
		(0.022)
L.RS-Drought	-0.068	-0.065
	(0.035)	(0.039)
DS-Drought	0.065*	
	(0.031)	
L.Boko Haram Activity	0.001	0.001
	(0.000)	(0.000)
Population	-0.068	0.032
	(0.178)	(0.177)
INDIRECT		
L.Grass	0.299***	0.275**
	(0.083)	(0.091)
L.RS-Drought Niger's grasslands (dist)	0.756	0.676
	(0.460)	(0.460)
L.Grass × L.RS-Drought Niger's grasslands (dist)	**-0.356****	**-0.335***
	(0.131)	(0.134)
L. Crop size		0.970
		(0.569)
GS-Drought		-0.043
		(0.025)
L.Crop size × GS-Drought		**0.009**
		(0.031)
L.RS-Drought	0.078*	0.074
	(0.038)	(0.042)
DS-Drought	-0.055	
	(0.034)	
L.Boko Haram Activity	-0.009**	-0.010**
	(0.003)	(0.003)
Population	-0.321	-0.615
	(0.559)	(0.543)
TOTAL		
L.Grass	0.327***	0.305**
	(0.086)	(0.093)
L.RS-Drought Niger's grasslands (dist)	0.489	0.429
	(0.320)	(0.317)
L.Grass × L.RS-Drought Niger's grasslands (dist)	**-0.177**	**-0.160**
	(0.123)	(0.126)
L. Crop size		0.479
		(0.469)
GS-Drought		-0.018
		(0.012)
L.Crop size × GS-Drought		**0.021**
		(0.015)
L.RS-Drought	0.010	0.008
	(0.007)	(0.008)
DS-Drought	0.010	
	(0.006)	
L.Boko Haram Activity	-0.008**	-0.009**
	(0.003)	(0.003)
Population	-0.389	-0.583
	(0.433)	(0.430)
ρ	**0.081***	**0.090***
	(0.041)	(0.040)
Log-lik	1471.06	1469.98
Obs	3355	3355
Hausman χ^2	44.86	56.17
Hausman p-value	0.00	0.00
Cell fixed effects	Yes	Yes
Time fixed effects	Yes	Yes
BIC	-2698.57	-2631.46

Notes: * p<0.05, ** p<0.01, *** p<0.001. Total, direct and indirect effects were estimated using a spatial Durbin model with spatial and individual fixed effects. Robust standard errors (in parentheses) are clustered at the cell level. The outcome variable is a dummy variable indicating the incidence of conflict between herders and farmers during the dry season, according to the Nigeria watch database. It takes the value "1" if there is at least one conflict episode in the cell during the year considered. *Source: Author's compilation.*

7 Robustness Checks

7.1 Alternative Specifications of the Logistic Model

The logistic model results using alternative independent variables are presented in **Annex F**. In column (1), the drought variable is divided by the log distance to the Niger-Nigeria border. This transformation reduces the weight of cells that have less chance to receive nomadic herders from Niger. The negative effect of Niger's droughts on the risk of conflict persists; a 0.1 unit increase in the distance-weighted drought measure reduces the risk of herder-farmer conflict by 0.63 percentage points. Due to the highly disaggregated nature of the data, herder-farmer conflicts happen to be rare events. In this setting, King and Zeng (2001) show that using a non-linear estimation strategy can lead to biased results. Yet, column (2) shows that the coefficients' sign and significance are not modified when a linear probability model[36] is used instead of the logistic regression[37]. In columns (3) and (4), alternative measures of drought are used. Column (3) shows that temperature rise negatively affects the risk of conflict which corresponds to our previous result. However the coefficient is not significant, probably because temperature is not the primary determinant of phytomass (McGuirk and Nunn, 2020). Column (4) shows a significant effect of increased precipitation on the risk of conflict, which is consistent with our previous results when using the SPEI measure.

Annex G presents the logistic model results using Acled as an alternative database to construct the dependent variable. In column (1), a herder-farmer conflict is defined as any Acled event whose description contains at least one word or combination of terms that are specific to this type of conflict.[38] The sign and significance of the coefficient associated with pasture scarcity in Niger are not modified. The coefficient's magnitude is slightly higher. Column (2) presents the results obtained while using Eberle et al. (2020) categorization of herder-farmer conflicts.[39] Again, our results stay unchanged with a slightly higher coefficient. A one standard-deviation increase in the drought index of Niger's grasslands during the rainy season decreases by 0.6 percentage points the risk of herder-farmer conflict in Nigeria in the next dry season (holding all the control variables at their mean). In columns (3) and (4), a quadratic term is added. In both specifications and similarly to the baseline logistic model, the squared term presents a positive and significant coefficient.

[36]When using a LPM model, the estimates are not constrained to the unit interval. When the dependent variable is binary, it may lead to biased and inconsistent estimates. Horrace and Oaxaca (2006) show that the LPM is unbiased and consistent when no predicted probabilities lie outside the unit interval. According to the baseline specification estimates, this is the case in our model since the average probability of herder-farmer conflict in a cell lies within the $(-0.20, 0.45)$ interval.

[37]We note a larger marginal effect of changes in the distance-weighted measure of drought in Niger's grasslands. This difference does not affect our conclusions and is linked to the fact that the predicted probabilities of conflict can be defined outside $[0;1]$ in a linear probability model.

[38]"crop" and "cattle", "land" and "cattle", "crop" and "herd", "farmer" and "herd", "agri" and "pastor", "farmer" and "transhumance", "farm" and "nomad", "cattle" and "invade", "nomad" and "farm", "grazing".

[39]Eberle et al. (2020) define herder-farmer conflicts as events that include at least one of the following keywords: land dispute, dispute over land, control of land, over land, clash over land, land grab, farm land,land invaders, land invasion, land redistribution, land battle, over cattle and land, invade land, over disputed land, over a piece of land, herd, pastoral, livestock, cattle, grazing, pasture, cow, cattle, farm, crop, harvest.

7.2 Alternative Specifications of the Spatial Model

Alternative specifications of the spatial model are presented in **Annex I** for robustness checks. Column (1) presents the results when the presence of a curvilinear (U-shape) effect of the interest variable is tested. A quadratic term is included and interacted with the binary variable indicating the presence of grassland. The coefficients associated with the quadratic term are never significant, suggesting that the previously found U-shaped effect of the climatic conditions in Niger's grasslands disappears when the model controls for spatial spillovers.

Nigeria is a federal country and each of the thirty-six Nigerian states can implement its legislation on nomadic pastoralism. Omitted variables related to state-level differences could skew the standard errors. In column (2), standard errors are clustered at the level of Nigerian States. The coefficient associated with the interaction term of interest in the cell becomes significant at the 5% level, which suggests that heterogeneous State level characteristics matter for the opportunity cost channel. The sign, magnitude, and significance of the other results remain unchanged.

The distance to the border is included in the construction of the variable of interest to capture that nomadic herders from Niger seldom travel very far into the Southern part of Nigeria. To verify that the effect of the distance to the border on conflicts does not drive our results, the SDM model is reproduced using the drought index not divided by the distance to the border. The results are reported in columns (3) and (4). Their significance and sign align with the findings of our baseline specification, including the recurrent inconsistency of the opportunity cost channel.

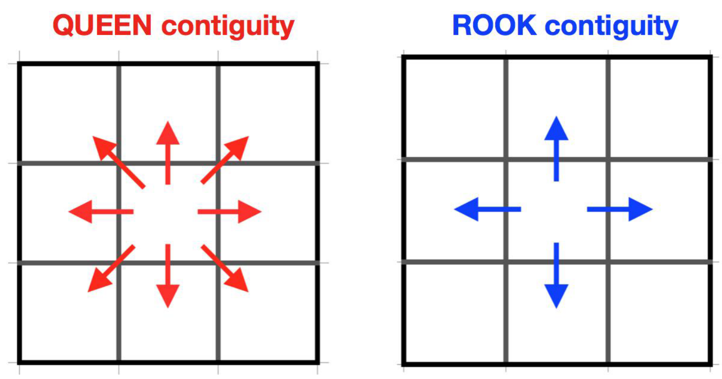
We are interested in the flow of pastoralists from Niger following the rarefaction of Nigerien pastures. We verify that the results of the spatial model are linked to the drought affecting the pastures and not the rest of the Nigerien territory. Column (5) presents the results of the SDM model using the average level of rainy season's drought in Nigerien areas where there is no grassland. The coefficients associated with the interaction terms are not significant, which confirms that climate shocks affecting Nigerien pastures drive our main results.

7.3 Alternative Weight Matrix

In this section, we modify the definition of what constitutes a neighbor and reproduce our main specification. The objectives are twofold: to provide methodological justifications to the choice of the weight matrix in our baseline model and to analyze how modifications of the spillovers' scale affect our results (LeSage and Pace, 2014a). The results of the spatial Durbin model using different row-standardized spatial weight matrices are reported in **Table 6**. Each column reports the direct, indirect, and total effects of the variables of interest using inverse distance weight matrices with different distance cutoffs. Since we use a gridded representation of Nigeria, column (1) is limited to first-order neighbors, column (2) to second-order neighbors, column (3) to third-order neighbors, and column (4) to fourth-order neighbors. Column (5) considers the whole Nigerian territory.

The estimates and inferences from spatial regression models are often considered sensitive to the spatial weighting matrix (LeSage and Pace, 2014b). The selection of a Queen contiguity spatial weight matrix is theoretically motivated, considering the hypothesis on the nature of spatial interactions. Indeed, we are interested in the choices that a breeder make during his transhumance between staying in a cell and moving to its neighbor according to the information at his disposal. Therefore, the nearest neighbor contiguity weight matrix appears to be the most appropriate measure to study these local spillover effects. Also, unlike Rook contiguity, Queen contiguity includes diagonal breeder moves (see **Figure 7**).

Figure 7: Definition of Queen and Rook Contiguity



Source: Ardilly et al. (2018).

The coefficient ρ is not significant in columns (2), (4), and (5), suggesting that these SDM models can be further simplified to spatial lag of X models (SLX). Results of the SLX models are presented in **Table 7**. **Table 6** and **Table 7** report the Bayesian Information Criterion (BIC) associated with the most suited spatial model for the considered spatial weight matrix. Models having a smaller BIC indicate a better model fitting and model parsimony. The BIC reported for different cutoffs of inverse distance matrix are generally bigger than the one of our baseline model ($BIC = -2698.57$, see **Table 5**). One exception is the SDM model with a cutoff of the weighting matrix of 270km. However, this difference is marginal and theory should be the driving force behind the selection of the spatial weight (LeSage and Pace, 2014b).

The results are generally in line with the ones of our baseline spatial model concerning local spillovers (i.e., immediate neighbors). The magnitude of the indirect effects increases with the size of the distance cutoff because they reflect an average of spatial spillovers cumulated over more neighbors. Concerning the direct effects, a significant ($p<0.05$) positive effect of the interaction term is observed when the neighborhood is limited to contiguous neighbors (column 1 of *Table 6*). Concerning the total effects, a significant ($p<0.05$) positive effect of the interaction term is observed for the inverse distance matrix with no cutoff (column 3 of *Table 7*). When a larger number of neighbors is considered, the analysis explores global spillovers(LeSage, 2014). Local spillovers' analysis is linked to short-term decision making, while the analysis of global spillovers takes into account a larger set of future prospects and past experiences of herders during transhumance. The direct effect of drier climatic conditions in Niger's grasslands for Nigerian cells with pasture is only significant at a very local scale (direct neighbors). It suggests that predatory behaviors for the remaining grasslands may span from local decision making. In column (3) of *Table 7*, the total effect of drier climatic conditions in Niger's grasslands for Nigerian cells with pasture is negative and significant at the 5% level. Also, drier climatic conditions in Niger's grasslands increase the risk of herder-farmer conflict close to pasture-less Nigerian cells. These results suggest that grasslands, and more precisely the presence of alternative grasslands, can reduce the risk of herder-farmer conflict by reducing the economic interest to resort to predatory behavior.

Table 6: Alternative Specifications of the Spatial Weights - SDM Models

	SDM Inv. Dist. d = 90 km	**SDM** Inv. Dist. d = 180 km	**SDM** Inv. Dist. d = 270 km	**SDM** Inv. Dist. d = 360 km	**SDM** Inv. Dist. Total
	(1)	(2)	(3)	(4)	(5)
Direct					
L.Grassland	0.031	0.030	0.028	0.030	0.032
	(0.027)	(0.028)	(0.027)	(0.028)	(0.027)
L.RS-Drought Niger's grasslands (dist)	-0.297	-0.328	-0.332	-0.364	-0.357
	(0.315)	(0.264)	(0.240)	(0.221)	(0.216)
L.Grassland × L.RS-Drought Niger's grasslands (dist)	0.182*	0.161*	0.156	0.153	0.157
	(0.087)	(0.080)	(0.081)	(0.082)	(0.082)
Indirect					
L.Grassland	0.284***	0.518***	0.591**	0.879**	2.038**
	(0.083)	(0.156)	(0.208)	(0.287)	(0.718)
L.RS-Drought Niger's grasslands (dist)	0.796	1.094*	1.270*	1.612*	4.106*
	(0.487)	(0.534)	(0.581)	(0.648)	(1.723)
L.Grassland × L.RS-Drought Niger's grasslands (dist)	-0.361**	-0.484**	-0.574*	-0.729*	-1.973**
	(0.130)	(0.181)	(0.228)	(0.296)	(0.754)
Total					
L.Grassland	0.315***	0.548***	0.619**	0.908**	2.069**
	(0.087)	(0.156)	(0.206)	(0.287)	(0.717)
L.RS-Drought Niger's grasslands (dist)	0.499	0.766	0.938	1.248*	3.749*
	(0.314)	(0.410)	(0.483)	(0.568)	(1.637)
L.Grassland × L.RS-Drought Niger's grasslands (dist)	-0.179	-0.323	-0.418	-0.576*	-1.816*
	(0.119)	(0.174)	(0.216)	(0.278)	(0.739)
ρ	0.085*	0.113	0.169*	0.174	0.123
	(0.041)	(0.110)	(0.041)	(0.087)	(0.467)
Log-lik	1471.06	1473.87	1471.41	1469.94	1471.03
Obs	3355	3355	3355	3355	3355
BIC	-2698.57		-2699.28		
Controls	Yes	Yes	Yes	Yes	Yes
Moran	0.264	0.167	0.133	0.097	0.046
Moran p.val	0.000	0.000	0.000	0.000	0.000

Notes: * p<0.05, ** p<0.01, *** p<0.001. Spatial Durbin models (SDM). Robust standard errors (in parentheses) are clustered at the cell level. Cell and year fixed effects are included. Standard and spatially lagged controls at the cell level include the level of drought during the previous rainy season, the level of drought during the dry season, the activity of Boko Haram during the previous year (dummy variable), and the size of the population. The Moran's I statistic is calculated from the average incidence of herder-farmer conflict per cell for the whole period (2006-2016). *Source: Author's compilation.*

Table 7: Alternative Specifications of the Spatial Weights - SLX Models

	SLX Inv. Dist. d = 180 km	**SLX** Inv. Dist. d = 360 km	**SLX** Inv. Dist. Total
	(1)	(2)	(3)
Direct			
L.Grassland	0.028	0.027	0.029
	(0.027)	(0.027)	(0.027)
L.RS-Drought Niger's grasslands (dist)	-0.394	-0.441	-0.450
	(0.352)	(0.312)	(0.291)
L.Grassland × L.RS-Drought Niger's grasslands (dist)	0.151	0.132	0.133
	(0.078)	(0.076)	(0.076)
Indirect			
L.Grassland	0.495***	0.760***	1.735***
	(0.112)	(0.190)	0.419)
L.RS-Drought Niger's grasslands (dist)	1.085*	1.448*	3.376**
	(0.528)	(0.584)	(1.280)
L.Grassland × L.RS-Drought Niger's grasslands (dist)	-0.406*	-0.491*	-1.148*
	(0.176)	(0.234)	(0.528)
Total			
L.Grassland	0.524***	0.787***	1.764***
	(0.113)	(0.190)	(0.418)
L.RS-Drought Niger's grasslands (dist)	0.692*	1.008*	2.926**
	(0.331)	(0.419)	(1.097)
L.Grassland × L.RS-Drought Niger's grasslands (dist)	-0.254	-0.359	-1.015*
	(0.154)	(0.212)	(0.499)
Log-lik	1188.93	1187.34	1189.72
Obs	3355	3355	3355
Controls	Yes	Yes	Yes
BIC	-2183.03	-2179.85	-2184.61

Notes: * p<0.05, ** p<0.01, *** p<0.001. Spatial lag of X (SLX) models with robust standard errors (in parentheses). Cell and year fixed effects are included. Standard and spatially lagged controls at the cell level include the level of drought during the previous rainy season, the level of drought during the dry season, the activity of Boko Haram during the previous year (dummy variable), and the size of the population. *Source: Author's compilation.*

8 Conclusion

This article studies how pasture scarcity in Nigeria affects the risk of conflict between pastoralists from Niger and local farmers. The recent empirical literature on herder-farmer conflicts in Africa shows that sudden flows of breeders in search of resources to feed their herd destabilize informal arrangements between herders and farmers, increasing the risk of violence for the remaining resources. Regarding the flow of herders leaving Niger during the dry season, this study finds little to no evidence that a greater climate-related flow of transhumant pastoralists leads to a higher risk of herder-farmer conflict in Nigeria. Dryer conditions in Niger's pastures are associated with a significantly smaller risk of herder-farmer conflict in Nigeria. This study finds evidence of a U-shaped relationship between climatic shocks (floods and droughts) and conflicts. however, these results hardly coincide with the mechanism of competition for the remaining resources.

Using spatial econometric techniques, the second part of this article analyzes the spatial heterogeneity of the risk of conflict between herders and farmers depending on the proximity to pastures. Some evidence is found of conflict for the remaining resources following drought in Niger's grasslands. However, the magnitude of this effect is low and very local, suggesting that competition for the remaining grasslands is not the primary driver of conflict between nomadic pastoralists from Niger and farmers from Nigeria. Drier climatic conditions in Niger's grasslands are associated with a significantly lower risk of herder-farmer conflict in areas close to pastures. Proximity to alternative grasslands reduces transhumance's cost, making movement a more rational choice than violent appropriation. Therefore, pasture scarcity in Nigeria could increase the risk of herder-farmer conflict following massive climate-induced movements of pastoralists across the Niger-Nigeria border. Finally, climatic shocks affecting the farmers' incomes are positively by not significantly associated with the risk of herder-farmer conflict, suggesting that the economic constraint put on farmers does not influence the risk of herder-farmer conflict.

Comparing these results with the pastoral policies carried out in the region provides elements of reflection on the sustainability of Nigeria's position on cross-border transhumance. In many parts of Nigeria, cross-border transhumance is considered a threat to national security as local and foreign nomadic pastoralists are merged into the same invader-farmer rhetoric (Chiluwa and Chiluwa, 2020).[40] Herders' movements to Nigeria, justified by climatic constraints in the departure area, are considered archaic and vectors of conflict with local farmers for the remaining grasslands. This article suggests that this rhetoric could be self-fulfilling. Since 2006, the amount of pasture in Nigeria is decreasing, justified by an ambition to sedentarize herders and develop the agricultural sector. However, the disappearance of open grazing areas makes seasonal and climate-induced transhumance riskier, increasing the herder's incentive to chose predatory behaviors and the likelihood of herder-farmer conflict.

Finding a solution to the herder-farmer crisis in Nigeria is important for the economy and the food security of the country and its neighbors. In the coming years, increasing pressure on land, higher temperatures, and depleted water resources are expected to move farms from high to low agro-ecological zones (Kurukulasuriya and Mendelsohn, 2008; Carrão et al., 2016). This change in the socio-ecological organization of spaces will likely increase encounters between breeders and farmers.

[40] In the Sahel, the Fulani ethnic group is the most represented among pastoralists. Added to the land-use issues, ethnic and religious differences between farmers and herders generate a climate of cultural opposition in some regions, maintaining tensions and facilitating confusion.

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Appendices

A Correspondence Between the IPCC Land Categories and CCI-LC Maps Legends

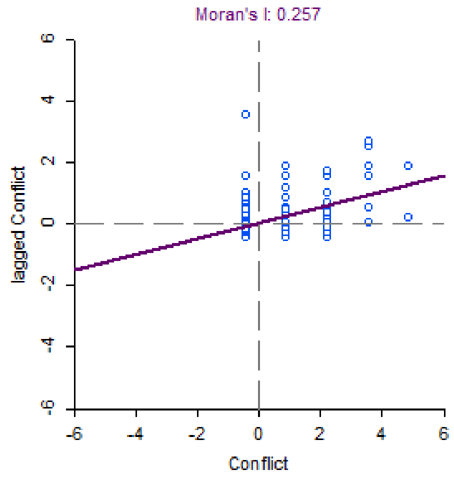
IPCC Classes	LCCS Legends Used in the CCI-LC Maps
1. Agriculture	Rainfed cropland
	Irrigated cropland
	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)
	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)
2. Forest	Tree cover, broadleaved, evergreen, closed to open (>15%)
	Tree cover, broadleaved, deciduous, closed to open (>15%)
	Tree cover, needleleaved, evergreen, closed to open (>15%)
	Tree cover, needleleaved, deciduous, closed to open (>15%)
	Tree cover, mixed leaf type (broadleaved and needleleaved)
	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)
	Tree cover, flooded, fresh or brakish water
	Tree cover, flooded, saline water
3. Grassland	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)
	Grassland
4. Wetland	Shrub or herbaceous cover, flooded, fresh-saline or brakish water
5. Settlement	Urban
6. Other	Shrubland
	Lichens and mosses
	Sparse vegetation (tree, shrub, herbaceous cover)
	Bare areas
	Water

B Descriptive Statistics Associated with the Main Variables

	(1) Mean	(2) Std.Dev.	(3) Obs	(4) Min	(5) Max
Herder-Farmer conflicts					
Total	0.043	0.203	3355	0.000	1.000
Dry season	0.031	0.173	3355	0.000	1.000
Rainy season	0.015	0.122	3355	0.000	1.000
Land cover					
Crops (proportion)	0.621	0.321	3355	0.000	0.999
Grasslands (proportion)	0.033	0.092	3355	0.000	0.705
Grassland (presence)	0.652	0.476	3355	0.000	1.000
Drought					
Nigeria - Rainy season $(t-1)$	0.118	0.778	3355	-1.963	2.314
Nigeria - Dry season (t)	0.535	0.905	3355	-3.089	2.995
Nigeria - Growing season (t)	0.138	0.870	3355	-2.507	2.606
Niger - Rainy season $(t-1)$	0.000	0.546	3355	-0.887	0.934
Niger - Rainy season $(t-1)$ (dist)	0.000	0.101	3355	-0.268	0.282
Other controls					
Boko Haram	0.248	2.122	3355	0.000	80
River lenght	0.181	0.197	3355	0.000	1.382
Roads length (log)	5.370	1.077	3355	0.000	6.857
Population size (log)	12.722	0.905	3355	10.150	15.255
Distance to the Niger-Nigeria border (log)	5.665	0.871	3355	3.314	6.825

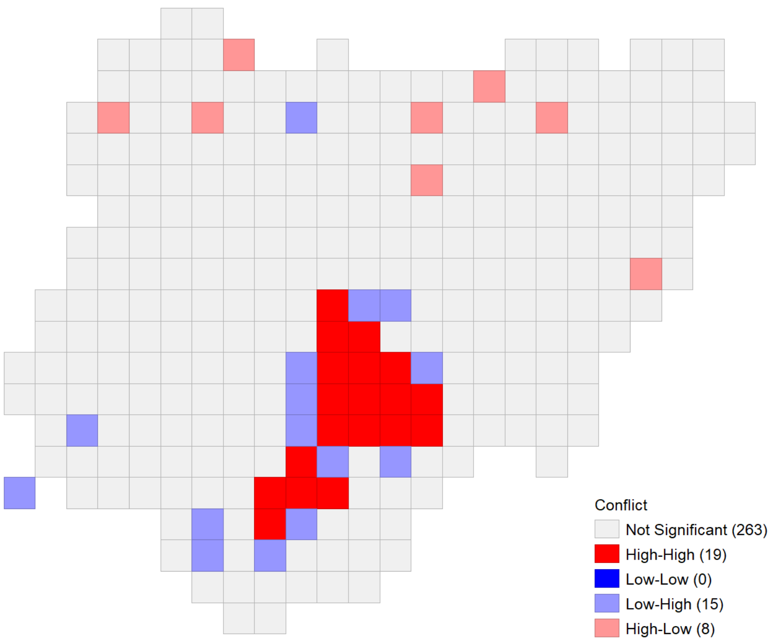
Notes: The unit of observation is the cell/year. The table presents some statistics of the main variables used in this study: mean (column 1), standard deviation (column 2), number of observations (column 3), minimum (column 4) and maximum (column 5) values. The dry season corresponds to the period October-May. The rainy corresponds to the period June-September. The growing season is defined by the main type of crop production of each cell. The drought measure corresponds to the inverted Standardized Precipitation Evapotranspiration Index (SPEI). *Source: Author's compilation.*

C Moran Scatter Plot for the Average Incidence of Conflict Between Herders and Farmers in Nigeria (2006-2016)



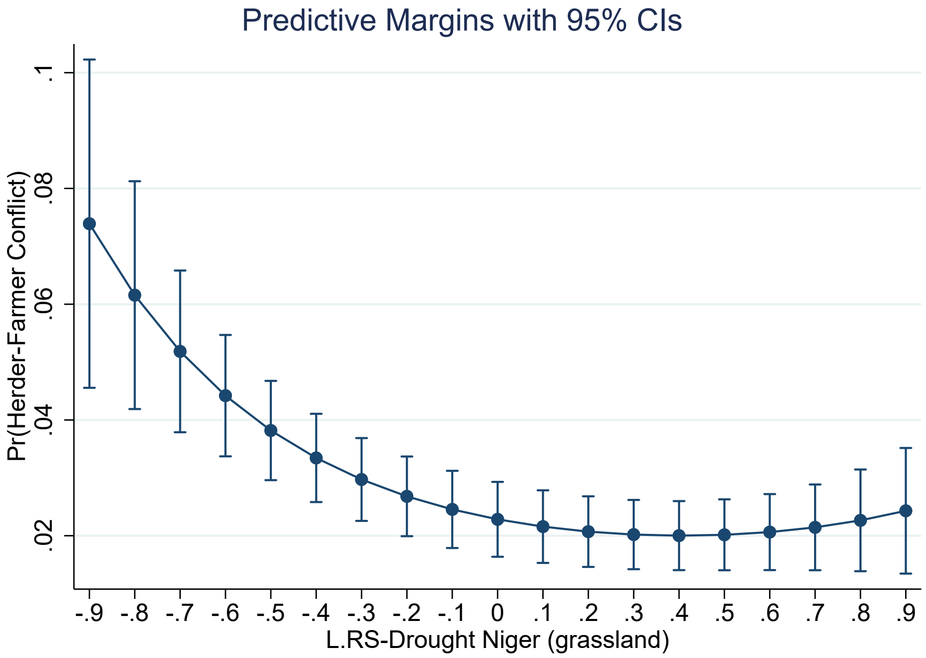
Notes: The variable tested is the cell's average incidence of conflict between herders and farmers between 2006 and 2016; the weight matrix is a first order queen contiguity matrix. The upper-right and the lower-left quadrants (lower-right and upper-left quadrants) correspond with positive (negative) spatial autocorrelation. *Source: Author's compilation.*

D Cluster Map for the Average Incidence of Conflict Between Herders and Farmers in Nigeria (2006-2016)



Notes: The variable tested is the cell's average incidence of conflict between herders and farmers between 2006 and 2016; the weight matrix is a first order queen contiguity matrix. Local Moran's I statistic significant at the 0.05 level using 999 permutations. *Source: Author's compilation.*

E Average Predicted Probabilities of Herder-Farmer Conflict Depending on the Level of Drought in Niger's Grasslands



Notes: Margins plot with capped spikes showing 95% confidence intervals. "Herder-Farmer Conflic" is a dummy variable indicating the incidence of conflict between herders and farmers during the dry season according to the Nigeria Watch database. It takes the value "1" if there is at least one conflict episode in the cell during the year considered. "L.RS-Drought Niger (grassland)" is the average level of drought in Niger's grasslands during the previous rainy season (centered at its mean); it corresponds to the inverted SPEI measure of (Vicente-Serrano et al., 2010).
Source: Author's compilation.

F Alternative Specifications of the Independent Variables - Logistic Model

	Logit (1)	*LPM* (2)	*Logit* (3)	*Logit* (4)
L.RS-Drought Niger's grasslands (dist)	-3.433**	-0.099**		
	(1.197)	(0.032)		
L.RS-Temp Niger's grasslands			-7.715	
			(9.776)	
L.RS-Prec Niger's grasslands				1.786*
				(0.838)
Border Distance			0.530***	0.523***
			(0.155)	(0.155)
Log-lik	-420.16	1156.96	-417.61	-415.46
Obs	3355	3355	3355	3355
Controls	Yes	Yes	Yes	Yes

Notes: * p<0.05, ** p<0.01, *** p<0.001. Results were estimated using logistic (columns 1-6) and linear (column 7) models. Robust standard errors are in parentheses. The outcome variable is a dummy variable indicating the incidence of conflict between herders and farmers during the dry season according to the Nigeria watch database. It takes the value "1" if there is at least one conflict episode in the cell during the year considered. Controls include the SPEI during the previous rainy season, the dry season's SPEI, the population size, the average roads' length, the average rivers' length, and an indicator of last year's activity of the group Boko Haram. *Source: Author's compilation.*

G Alternative Specifications of the Dependent Variables - Logistic Model

	Acled (1)	Eberle et al. (2020) (2)	Acled (3)	Eberle et al. (2020) (4)
L.RS-Drought Niger (grassland)	-0.705**	-0.726**	-0.696***	-0.741***
	(0.262)	(0.234)	(0.205)	(0.198)
L.RS-Drought Niger (grassland) sq.			0.763*	0.546^{a}
			(0.314)	(0.308)
Log-lik	-362.92	-406.74	-360.31	-405.25
Obs	3355	3355	3355	3355
Controls	Yes	Yes	Yes	Yes

Notes: a p<0.1, * p<0.05, ** p<0.01, *** p<0.001. Results were estimated using logistic regression. Robust standard errors are in parentheses. The "Acled" dependent variable defines herder-farmer conflict as events defined by Acled with at least one of the following (association of) key words: *"crop" and "cattle", "land" and "cattle", "crop" and "herd", "farmer" and "herd", "agri" and "pastor", "farmer" and "transhumance", "farm" and "nomad", "cattle" and "invade", "nomad" and "farm", "grazing"*. The conflict variable proposed by Eberle et al. (2020) was constructed similarly but with a different list of key words that pertain to resources and competition: *"land dispute", "dispute over land", "control of land", "over land", "clash over land", "land grab", "farm land", "land invaders", "land invasion", "land redistribution", "land battle", "over cattle and land", "invade land", "over disputed land", "over a piece of land", "herd", "pastoral", "livestock", "cattle", "grazing", "pasture", "cow", "cattle", "farm", "crop", "harvest"*. Controls include: the level of drought during the previous rainy season and during the dry season, Boko Haram activity during the previous year (dummy variable), population size, road length, river length and distance to the Niger-Nigeria border.
Source: Author's compilation.

H Heterogeneous Effects of Climatic Events Affecting Niger's Grassland on the Risk of Herder-Farmer Conflict - Logistic Model

	(1)	(2)	(3)	(4)	(5)
L.RS-Drought Niger (g)	-1.115**	-1.110**	-0.705***	-0.732**	-0.665***
	(0.339)	(0.408)	(0.188)	(0.229)	(0.190)
L.RS-Drought Niger (g) sq.	1.048*	0.728	0.817**	0.738	0.849**
	(0.533)	(0.635)	(0.297)	(0.378)	(0.296)
L.Grassland	0.575				
	(0.338)				
L.Grassland × L.RS-Drought Niger (g)	0.628				
	(0.406)				
L.Grassland × L.RS-Drought Niger (g) sq.	-0.364				
	(0.641)				
Mobile Pastoralism Suit.		1.232			
		(0.919)			
L.RS-Drought Niger (g) × Mobile Pastoralism Suit.		1.486			
		(1.342)			
L.RS-Drought Niger (g) sq. × Mobile Pastoralism Suit.		0.328			
		(1.994)			
Mobile Pastoralism Suit. (c)			1.232		
			(0.919)		
L.RS-Drought Niger (g) × Mobile Pastoralism Suit. (c)			1.486		
			(1.342)		
L.RS-Drought Niger (g) sq. × Mobile Pastoralism Suit. (c)			0.328		
			(1.994)		
Animal Husbandry Suit.				-1.644	
				(3.374)	
L.RS-Drought Niger (g) × Animal Husbandry Suit.				1.340	
				(3.692)	
L.RS-Drought Niger (g) sq. × Animal Husbandry Suit.				2.216	
				(5.670)	
Animal Husbandry Suit. (c)					-1.644
					(3.374)
L.RS-Drought Niger (g) × Animal Husbandry Suit. (c)					1.340
					(3.692)
L.RS-Drought Niger (g) sq. × Animal Husbandry Suit. (c)					2.216
					(5.670)
Log-lik	-405.97	-406.13	-406.13	-408.22	-408.22
Obs	3355	3355	3355	3355	3355
Controls	Yes	Yes	Yes	Yes	Yes

Notes: * p<0.05, ** p<0.01, *** p<0.001. Results were estimated using logistic regression. Robust standard errors are in parentheses. The outcome variable is a dummy variable indicating the incidence of conflict between herders and farmers during the dry season according to the Nigeria watch database. It takes the value "1" if there is at least one conflict episode in the cell during the year considered. "L.RS-Drought Niger (g)" is the level of drought in Niger's grassland during the previous rainy season (Vicente-Serrano et al., 2010). (c) indicates mean-centered variable. Indicator of the cell's suitability (Suit.) for animal husbandry and mobile pastoralism was obtained from Beck and Sieber (2010). Controls include: the level of drought during the previous rainy season and during the dry season, Boko Haram activity during the previous year (dummy variable), population size, road length, river length and distance to the Niger-Nigeria border. *Source: Author's compilation.*

I Alternative Specifications - Spatial Model

	(1)	(2)	(3)	(4)	(5)
L.Grassland	0.027	0.024	0.024	0.024	0.008
	(0.053)	(0.027)	(0.026)	(0.029)	(0.034)
L.RS-Drought Niger's grasslands (dist)	-0.217	-0.264			
	(0.399)	(0.290)			
L.Grassland × L.RS-Drought Niger's grasslands (dist)	0.185	0.173*			
	(0.104)	(0.079)			
L.RS-Drought Niger's grasslands (dist) sq.	-0.192				
	(1.780)				
L.Grassland × L.RS-Drought Niger's grasslands (dist) sq.	-0.368				
	(1.026)				
L.Grassland × L.RS-Drought Niger's grasslands			0.030*	0.030*	
			(0.015)	(0.014)	
L.Grassland × L.RS-Drought Niger (no grasslands)					0.019
					(0.024)
WL.Grassland	0.278***	0.276**	0.271**	0.271**	0.308***
	(0.083)	(0.104)	(0.084)	(0.104)	(0.091)
WL.RS-Drought Niger's grasslands (dist)	0.611	0.697			
	(0.561)	(0.468)			
WL.Grassland × L.RS-Drought Niger's grasslands (dist)	-0.328*	-0.335**			
	(0.143)	(0.109)			
WL.RS-Drought Niger's grasslands (dist) sq.	0.966				
	(2.863)				
WL.Grassland × L.RS-Drought Niger's grasslands (dist) sq.	-0.195				
	(1.540)				
WL.Grassland × L.RS-Drought Niger's grasslands			-0.044*	-0.044**	
			(0.020)	(0.014)	
WL.Grassland × L.RS-Drought Niger (no grasslands)					-0.045
					(0.034)
ρ	0.081*	0.081*	0.082*	0.082*	0.081
	(0.041)	(0.039)	(0.041)	(0.040)	(0.042)
Log-lik	1471.43	1471.06	1470.00	1470.00	1467.66
Obs	3355	3355	3355	3355	3355
Hausman χ^2	47.71	44.86	42.80	42.80	43.67
Hausman p-value	0.00	0.00	0.00	0.00	0.00
Cell fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
Cluster level	Cell	Admin	Cell	Admin	Cell

Notes: * p<0.05, ** p<0.01, *** p<0.001. Results were estimated using a fixed effects spatial Durbin model. Robust standard errors are in parentheses. The outcome variable is a dummy variable indicating the incidence of conflict between herders and farmers during the dry season according to the Nigeria watch database. It takes the value "1" if there is at least one conflict episode in the cell during the year considered. Controls (standard and spatially lagged) at the cell level include: the level of drought during the previous rainy season, the level of drought during the dry season, the activity of Boko Haram during the previous year (dummy variable), and the size of the population. *Source: Author's compilation.*