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Econometric study on the impact of rainfall variability on security in the Sahel region

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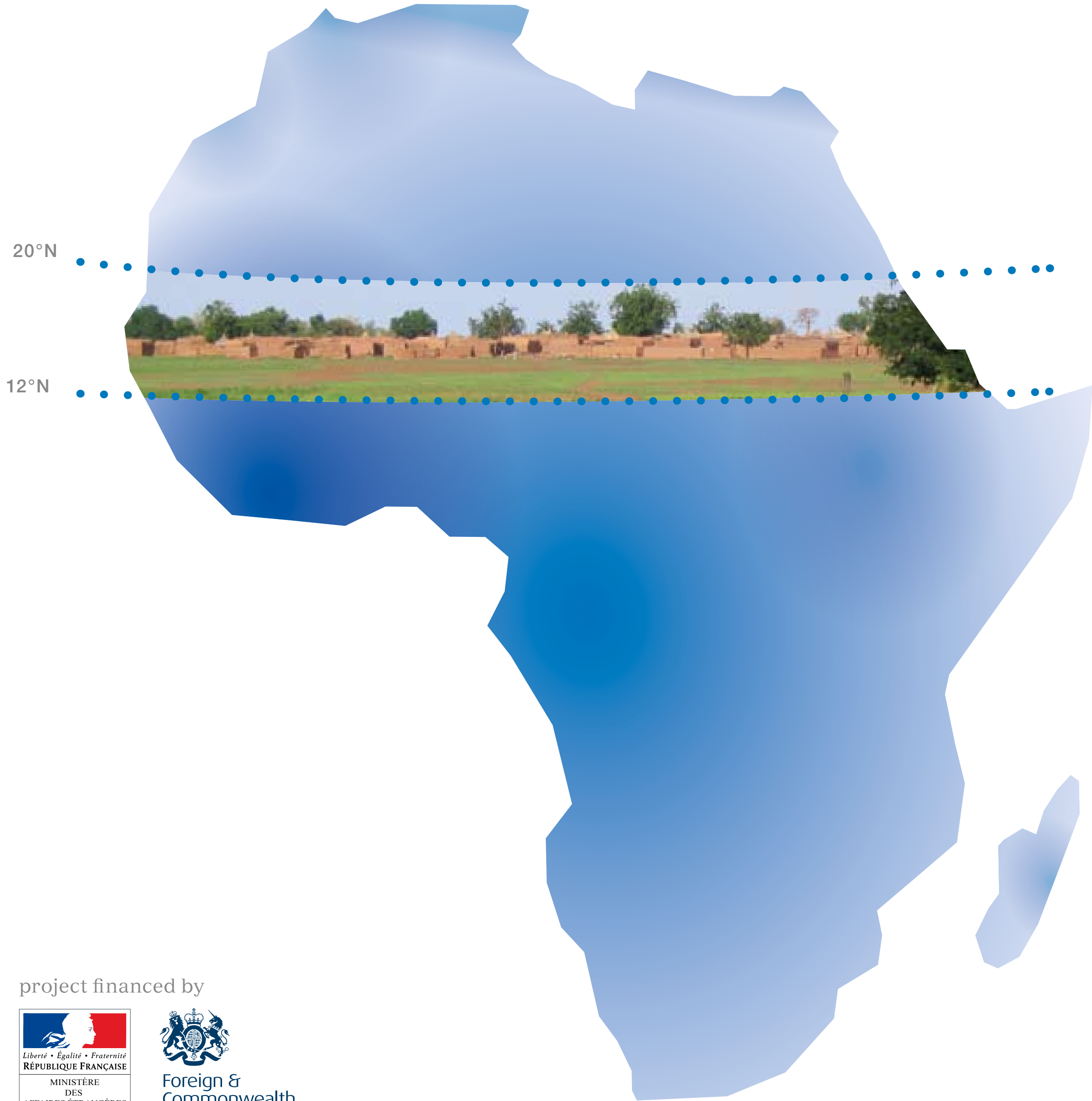

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Abstract

This paper proposes a two-channel model to identify and analyse the impact of climate variability on security events. Specification of this model is based on a review of quantitative literature, and a specific focus has been made for the results obtained from this model to contribute to a mapping of vulnerability. In this model rainfall deviations are assumed to act as a trigger of security events through an agricultural production growth channel and urbanisation growth channel. Results show an overall influence of past rainfall deviations on security, with agricultural production growth being the dominant channel, while urbanisation growth proved to a have very low influence. The strong importance of countries' socio-economic conditions in determining security vulnerabilities is highlighted. However, the quantitative estimations appear statistically weak limiting its interpretive power.

1 Introduction

Social scientists have been split between several approaches when trying to model links relating climate to security risk, each having advantages and drawbacks. The first generalist approach used conceptual models in order to give a large picture of all possible interactions between climate changes and security events (see for example Perch-Nielsen, 2004). These models are designed based on intuition and case-study analyses, and the wide array of connections documented is discussed theoretically. A second family of approaches tried to model explicitly how the behaviour of people impacts security. This comes with an a priori on how people are reacting to events based on rational benefit-cost analysis, as for example in Collier and Hoeffer (2002). They argue that, following a shock that has lowered income, people in the developing world are more prone to join rebels as their opportunity cost to stay in the official system decreased.

The third family of approaches are quantitative models, which are used as a tool to assess a theoretical or intuitive relationship, and to give some idea on the degree of sensitivity of the tested relationship. These models are simplifications of a complex reality, as they focus on simple forms of equations (called reduced-form equations), and because most of them are based on probabilistic assumptions that do not model human behaviour well. Nevertheless, their main intention is to provide estimates of a set of coefficients that are fitting best investigated relationships to observations.

As such, quantitative models are interesting for the scope of this project as they can provide, based on observations, an attempt to assess the existence of an influence of climate on security, and of the size of its effect. Results can furthermore be of specific interest in quantifying and localising vulnerabilities. To map a country-specific relationship between security and a set of socio-economic and climate variables, a first strategy would actually be to aggregate these variables, assuming a weight of one for each variable. But nothing can insure that weighting conditions are not different, for example it can be argued that GDP per capita is a more important factor than population growth. As a supplementary view, econometric models can estimate, from past time-series data, weights relating the set of socio-economic-climate variables to security events, thereby giving a more precise aggregation for an index.

Following is a review of the quantitative econometric literature (part 2). Main points of this review are used to design a model, where climate is assumed to act as a trigger of security events through multiple channels of interest (part 3). A specific model is presented in a two-channel context for countries of the Sahel band (for this study the region lying between 12°N and 20°N), where rainfall deviations are assumed to trigger security events through channels of agricultural production growth and urbanisation growth (part 4). Results provide insights on the pertinence of these relationships (part 5.1 & 5.2). The importance of countries' socio-economic characteristics and their interpretation in terms of mapping vulnerability are discussed in part 5.3. Part 6 concludes.

2 Literature review

Quantitative attempts to assess and quantify a relationship between climate evolutions and security issues are not yet very numerous. In a recent survey, Gleditsch & al (2008) presented an inventory of 14 studies. Four of them are specifically related to sub-Saharan countries, a low-income region where the effect of climate change on security[1] are assumed be the strongest (Solana, 2008). Although a recent issue, it is an actively debated one and the number of studies should increase in the years to come. Nevertheless, existing studies are providing some guidance to relative advantages and drawbacks of the various approaches.

Papers can be divided into those having emphasized on a long-term view of the climate-security relationship and those having focused on a short-term view, underlining two theoretical assumptions. On one hand, long-term trends in climate, through their influences on renewable resource scarcity, are assumed to induce people to struggle more for resources, thereby increasing the baseline risk of security event occurrence. This argument finds its roots in the neo-Malthusian theory[2]. On the other hand, short-term studies try to identify variations (short-term) in climate as a possible trigger of security events.

From a conceptual view, these two approaches are complementary, as pointed out in the Solana report. Nevertheless, while short-term trigger effects of climate on security sound intuitively convincing given the difficulty of people to adapt smoothly to climate anomalies, in contrast the long-term view is widely criticised by several authors, such as Theisen (2008) and Hendrix & Glazer (2008). It is indeed far from obvious that long-term climate changes will increase difficulty to access renewable resources and lead to conflict, given that long-term changes give time for people to adapt, for example by using innovation potentialities.

2.1 Weak empirical evidence for the long-term view

Looking at the models focusing specifically on the long-term effect of climate changes on security, Hauge & Ellingsen (1998), in a widely cited paper, gave some support to the neo-Malthusian assumption. The authors performed a large cross-country analysis including sub-Saharan countries, where long-term changes in climate are assumed to be captured by resource scarcity variables, such as land degradation, deforestation and freshwater availability. Estimation leads the authors to conclude that these variables, in combination with population density, were increasing the risk of civil conflict.

These results of Hauge & Ellingsen were not confirmed by other studies. Among them, Esty et al (1998), in their work for the Phase II of the Political Instability Task Force, did

1 While these papers are using various variables to catch changes in climate, the variable for security is always an indicator of conflict, either civil, inter-state or pastoral.
2 The neo-Malthusian theory explains that increase in population density implies that people are more numerous to share a dwindling resource stock, thereby leading to security issues.

not succeed to identify a direct link between several measures of resource scarcity and internal tension. As pointed out by Gleditsch (2008), several other studies have found counter-intuitive results, for example de Soya (2002) estimated that an increase in renewable resource wealth leads to an increase in the risk of conflict. Besides, in a very convincing study, Theisen (2008) tried to reproduce the results of Hauge & Ellingsen using the same dataset, but it proved to be impossible, suggesting a very careful interpretation of the resource scarcity hypothesis.

One of the major technical difficulties of long-term models lies in the data availability. As pointed out by Gleditsh et al (2008), testing the assumption of resource scarcity is constrained by a limited set of dynamic measures of resource scarcity, and by data quality of variables such as freshwater or crop yields. Moreover, adaptive characteristics of a population have to be taken into account in order to adequately assess this kind of relationship.

2.2 Recent focus on the role of climate as a trigger of conflict has been more promising

Studies looking at short-term effects of climate have especially concentrated on the poorest regions of the world such as sub Saharan African countries, assuming that livelihood conditions are more sensitive to climate variation in these regions.

The use of climate variables as a trigger of civil conflicts has been made by Miguel et al (2004). The aim of the authors was to give an interpretation of the statically documented role of GDP growth in explaining conflicts in SSA countries: a decrease in GDP in developing countries can be seen as an increase in the opportunity cost of poor people to join rebel groups, or as an indicator of deterioration of state capabilities (see Fearin & Laitin 2003). Previous statistical attempts to address this issue were often biased, as the use of eco/socio/institution explanatory variables including GDP growth leads to endogeneity problems between the set of explanatory variables. Instead of using GDP growth in their model, Miguel et al proposed to use the correlated part of GDP growth with rainfall: as rainfall is clearly exogenous to the model, so is the part of GDP growth correlated with rainfall. While the results of Miguel gave some support to the opportunity cost interpretation of GDP as a factor leading to civil conflict, their result can also be understood as evidence of the trigger effect of climate on conflict through the GDP channel.

Hendrix & Glazer (2008) have been inspired by the work of Miguel et al when they proposed to assess for SSA the climate-civil conflict link, in a model testing for both short-term and long-term effects of climate on conflicts. Results on long-term effects were not fully convincing (climate suitability is acting in a consistent way to explain conflicts, but higher freshwater resources are increasing risk of conflict). At the opposite, rainfall deviations prove to be a statistically significant trigger explaining the probability to observe a civil conflict the following year, confirming former results of Miguel et al. In addition, they showed that the inferred probability to observe a conflict was far more sensitive to short-term rainfall deviations than to resource scarcity indicators.

The role of rainfall has also been confirmed in a higher geographical resolution analysis. Meier & Bond (2005) looked at factors explaining the pastoral conflicts in the Karamoja cluster, comprising Ethiopia, Kenya and Uganda. From annual rainfall observation, they found that the end of the dry season, January to March, was a period correlated with a substantial increase in human deaths and livestock losses. Data indicated highest shortage of forage during this period, suggesting therefore that pastoralists' mobility is highest during this period increasing security tensions.

2.3 Where does the literature stand?

Ideally, these quantitative models might be used to assess conceptual models, and to provide a view of relative importance of channels described. However, the complexity of links between climate and security issues, as illustrated in the conceptual models of Perch-Nielsen (2004), contrast with the reduced-form equations used in econometric models. Feedback loops are for instance difficult to estimate in these models, and relationships between climate and security are most of the time addressed in a linear way.

Amongst improvements proposed by Gleditsch et al (2008), they argued for an increase in the use of satellite imagery to build dataset: lack of dynamic resource scarcity variables, data quality and lack of observations within time-series limit the power of statistical analysis (this is particularly the case when analysing SSA countries). They also proposed to use more local data, Meier et al (2004) showing that a higher degree of resolution was needed when working on pastoral conflicts, while most studies are using aggregated national data. Nevertheless, increasing the resolution of analysis to produce a unified framework relating climate to security issues might just be transferring the problem, because focusing on more local conflicts might miss those that are finding their roots at state level.

Regarding non-linearity, some authors have tried to address this issue by using dummies to mechanically amplify the effect of a large climate anomaly or by using interaction terms (Hendrix et al), but nothing insured that it is a well-fitted form of non-linearity. A more robust and systematic consistency-check of non-linearity forms than previously used should help to develop better non-linearity structures. Last but not least, papers reviewed here were using conflict, civil, intrastate or pastoral, as the dependant variable, while security issues can be defined in broader terms and this should be reflected in the dependant variable. Finally, climate can trigger a security event through several transmission channels, but until now econometric models have only documented influence through GDP growth.

3 Proposed model structure and related assumptions

The general idea of quantitative models is to use econometric procedures[3] (algorithms) in order to fit with the maximum likelihood relationships of a conceptual model to observed data. One can therefore define a broad structure model in which several conceptual models can be tested, then select an estimation technique, and finally collect data in order to perform the estimation.

1 We choose a model structure consistent with the role of climate change as a trigger of security events, given its stronger statistical relationship than the long-term effect of climate change models. We also defined our model based on Miguel et al (2004), as it is the only model from the previous survey that can look at the effect of climate through channels. A channel approach allows for a finer view on the ways in which climate triggers security events, and also, provided further assumptions, to deal with multiple channel

3 Cross-country estimations can be performed with the use of ordinary linear regressions (OLS), or with more sophisticated estimation techniques such as generalized least square (GLS), which allow for more flexibility in statistical assumptions on variance and correlation.

analysis, thereby making quantitative models more robust[4] and slightly closer to complex conceptual models.

The structure of the conceptual model investigates the climate-security link as the "consequence of consequences" in a reduced-form:

- Climate variability (the independent variable) can have one direct effect on several variables (channels), and it is through these direct effects that climate impacts security (the dependent variable).
- The theory behind each relationship does not need to be formally addressed.
- No feedback loop is allowed between variables.

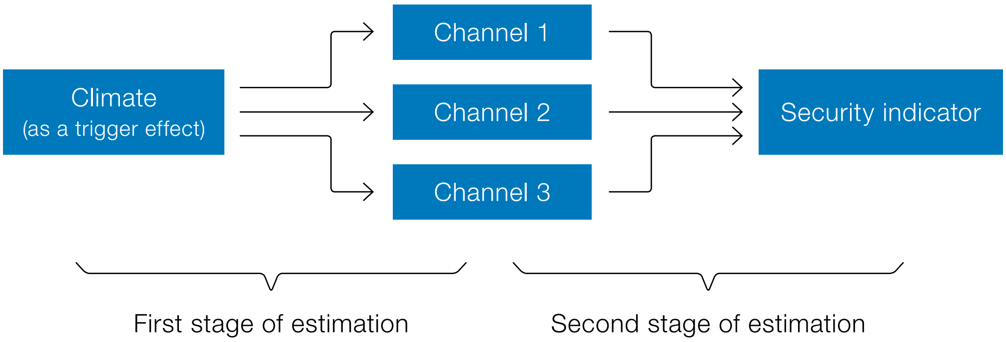

Figure 1

Structure of the reduced-form model

2 In terms of estimation, this model structure is very close to the one in Miguel et al (2004) and therefore well-fitted to the two-step least squared econometric estimation used by these authors: in the first stage, the relationship with climate variability for each channel is estimated, and in the second stage, the part of each channel explained by climate is used as a variable to estimate its relationship with security events. Further technical assumptions are needed to make the estimation procedure consistent. In particular, to allow for multiple channel analysis, interaction terms are used to obtain time- and country-varying sensitivities of first order channels to climate[5].

3 Regarding data, four sets of time-series data are collected. The focus on the trigger effect of climate implied that short-term indicators of climate conditions (i.e. variability) must be used, such as rainfall precipitations, temperature or climate anomalies indicators (droughts, etc.). The second set relates to variables directly affected by climate, referring in this model to channels and the security indicator, while the third set focus on variables possibly affecting sensitivities of direct relationship between climate and channels of investigation (the interaction terms). The last set of time-series data are control variables for other characteristics of countries explaining the evolution of the dependent

4 As argued by Miguel, estimation of the effect of climate on security through one channel only can bias results if climate has an effect on security through other variables. Nevertheless, multiple channels analysis will still be far from the high complexity of the true relationships, and therefore this approach will be of little help to deal with the issue of completeness.

5 The use of interaction terms is needed in the first-stage of estimation to allow for multiple channel estimation. Without interaction terms, as the model considers only one climate variable for the initial shock, the part of each channel explained by the climate variable would have the same variance and therefore the same information content, leading to inconsistency in the second stage of estimation. Therefore, to allow for multiple channel estimations, the sensitivity of each channel should be made dependent on time and accross country. To address this issue, we will make use of interaction terms linking in a multiplicative way the climate variable and other variables assumed to affect the overall sensitivity of the examined relationship. Second, an estimation procedure is correcting for non-constant variance in the residual accross countries (by applying PCSE cross-section weights when running estimations) : this is producing robust results but it also implies that the estimated relationship might deviate more from observational data than in a strictly linear estimation procedure.

variable. In terms of characteristics, these time-series variables should contain numerous observations and must be of the same frequency[6].

This specification should allow estimating the effect of climate on security through channels of transmission. The vulnerability maps can draw from these results integrating respective estimated weights *1)* variables affecting the sensitivity of various channels to climate variability, *2)* variables affecting the overall effect of climate variability on security, and *3)* the role of socio-economic variables in explaining vulnerabilities.

4 A specification for a two-channel model

Presentation of a two-channel model, quantified with the econometric two-stage least square procedure:

4.1 Specification

We test the assumption that climate variability (i. e. rainfall) has an effect on two variables, agricultural production growth and urbanisation growth, and that climate, through its effect on these two channels, acts as a trigger of security events. These two channels have been chosen for the following reasons.

Channel 1 Agricultural production growth: Agricultural production growth is likely to be a variable more directly linked to climate variability than the GDP growth variable used in Miguel et al. One can easily assume that the large share of the agricultural sector in SSA accounts for a large part of the variance in GDP growth, nevertheless a cross-country regression explaining GDP growth with climate should also control for country differences in the share of the agricultural production in GDP: otherwise, it implies that each country's GDP has the same sensitivity to climate regardless of the share of agriculture in GDP.

Channel 2 Urbanisation growth: Growth of urbanisation has not been a channel formally addressed in the econometric literature. We investigate its role with two concerns:

- The long-term urbanisation process is a source of peace in developing countries, with West-African countries succeeding to adapt to a strong urbanisation growth with a lag of three years (see Cours, J.M. and Snrech, S., 1998). However, the effect might be more ambiguous in the short-term for urbanisation dynamics that are caused by climate hazards for instance. Forcing people to move from rural to urban areas where these processes are not motivated by economic opportunities. This might in turn increase short-term instability in cities[7] Contrary to this, high mobility of rural population can also act as a buffer against instability, because forcing rurals not to move can lead to far more severe security issues.
- As a technical concern, it helps to illustrate the added-value of the multiple channel analysis presented here over the one-channel analysis. Indeed, Barrios et al (2006) have recently showed a statistical relationship linking urbanisation growth in SSA to rainfall. If one is using growth of urbanisation as the only channel linking climate to security, he will actually get the same results as Miguel et al who used the GDP

6 The higher the number of observations, the higher the robustness of the results by normal law assumptions.

7 Over the last five decades African countries have witnessed one of the fastest urbanisation rates ever observed. At the beginning of the "acceleration" in urbanisation, a large part of this growth was accounted for by rural-urban migration. Today, high urbanisation growth rates in Africa are predominantly natural (people born in urban areas). However, for the period (1970 – 200X) analysed in this paper rural-urban movements have been significant.

growth channel. This is due to the technical fact that estimated sensitivities are constant, implying that the variance of the part of GDP growth explained by rainfall is the same as the one with urbanisation growth. To avoid this spurious regression issue, multi-channel analysis makes use of interaction terms to make estimated sensitivities time-varying and country-varying, insuring therefore that variances are different. Furthermore this allows the testing of the respective significancy of these two channels together.

New characteristics of specification:

- While previous studies focusing on trigger effects have mostly emphasized the role of climate on conflicts (civil or pastoral), the definition of security retained in the Solana report is broader: it encompasses conflict but also migration, famine, health crisis, or external food-dependency issues. Based on the work on security events in the Sahel 1969-2007[8], we built a specific dependant variable, called indicator of security, which included events such as the famine episode in Niger in 2004-2005 and the health crisis in Burkina Faso between 2003 and 2007.
- We coded the security indicator variable as 1 when a security event begins and 0 otherwise, while previous literature coded it as 1 for the length of the conflict. Our approach focuses especially on the triggering effect of climate on conflict. The inconvenience of this choice is that it does not take into account the length of the conflict, but it is of second order in the strategy to assess climate trigger effects: once a conflict is triggered, it can find its own dynamic regardless of climate variability.
- We made use of several interaction terms, commonly used in previous studies, and consistent with our technical assumptions (cf. infra). However, the role of these interaction terms will be investigated in detail given their usefulness for producing maps: interaction terms can be seen as a way to estimate sensitivities based on several variables. The set of estimated coefficients of variables affecting sensitivity of one channel to climate variability could be weighted and used for the vulnerability mapping.

4.2 Description of time-series variables

Rainfall series are used as a trigger effect of climate in SSA. Data are provided by the UK Met Office Hadley Centre, and are disaggregated on a three region basis: eastern Sahel, central Sahel and western Sahel. The choice of data from three regions rather than national data has been made based on the high relevance of this dataset (monthly precipitation observations 1901-2006), and on the large homogeneous patterns of precipitations inside each region. To focus on short-term trigger effects, rainfall data are expressed in terms of deviations to their long-term mean (between 1901 and 1960), and normalized by their long-term mean to provide harmonized data between countries.

The indicator of security is coded as 1 when a security event occurs, 0 otherwise (see supra). Agricultural production growth is used from WDI World Bank, available at one year frequency since 1970 for most countries, while beginning in 1982 in Ethiopia, 1993 in Eritrea and 1990 in Djibouti. Urbanisation growth is taken from the FAO database. The remaining set of control variables, used to distinguish stuctural characteristics between countries in cross-country regressions, is taken from the WDI and the FAO. Fearon and Laitin (2002) provided detailed descriptions and sources of all control variables commonly

8 Salliot, E. "A review of past security events in the Sahel 1967 – 2007", (forthcoming), SICCS; SWAC Secretariat/OECD

used in conflict/security econometric literature. An indicator of drought event coming from the EM-DAT database on conflict has been used, and the index of political instability has been extracted from the Politi IV website.

Cross-country regressions for the 12 countries of the Sahel band are run on 262 periods of observations with a maximum period of estimation for one country ranging from 1978 to 2004. Ethiopia, Eritrea and especially Djibouti are countries for which the number of observations is lowest. Note, results for Djibouti are not presented given the very low number of observations.

5 Results

Results presented below are based on variables that have been selected for their statistical significance in terms of explanatory power on dependent variables. The first stage estimation examines independently the effect of rainfall on two variables, agricultural production growth and urbanisation growth. The second stage uses these two effects as variables explaining past occurrences of security events.

5.1 First stage estimations

5.1.1 Effect of rainfall on agriculture production growth

Best specification suggests that agricultural production growth *(AGR)* has been sensitive to rainfall deviations *(RAIN)*, and that this sensitivity has been modified across countries depending on the evolution of percentage of irrigated land *(IRR)* and of agriculture added-value per worker *(VA)*. The equation uses growth in production of crops *(CROP)* and livestock *(LS)* to control for different characteristics between countries:

$$AGR = 3.5 + RAIN \times (26.8 - 0.85IRR - 0.1VA) + 0.23LS + 0.19CROP$$

While the explanatory power of the overall equation remains low (only 24% of the growth of agricultural production is explained by this specification), all estimated coefficients are statistically significant at the 10% level (see table A1 in annex), and the regression signals a strong significant effect of rainfall deviations on agriculture production growth in the countries of the Sahel band: a variation of rainfall of -0.1 decreases the level of the production growth of -2.68ppt in the same year, all other things being equal. Several variables have been tried in interaction with rainfall deviations to transform across country and across time the level of sensitivity of agriculture to rainfall. Among them, the percentage of irrigated land and added-value of agricultural sector per worker, used as an indicator of agricultural productivity, is revealed to be statistically acceptable at the 5% level. An increase in 1.0 ppt of the percentage of irrigated land leads to a decrease of 0.85ppt of the sensitivity of agriculture to rainfall, while an increase in 100$ of the agricultural productivity implied a decrease in 10ppt of the same sensitivity.

From this estimation, figure 2 presents the evolution of sensitivity of agricultural production to rainfall in each country. It suggests that in a large number of countries sensitivity of their agricultural sector to rainfall variability did not change over time, their sensitivity line being flat. It also points to Nigeria and Sudan, where the sensitivity has decreased tremendously at least over the past decade, given a strong increase in their agriculture added-value per worker. Comparing level of sensitivity across countries in 2004, Eritrea, The Gambia and Senegal, had the strongest sensitivity of agriculture production growth to rainfall while Nigeria and Sudan had the lowest.

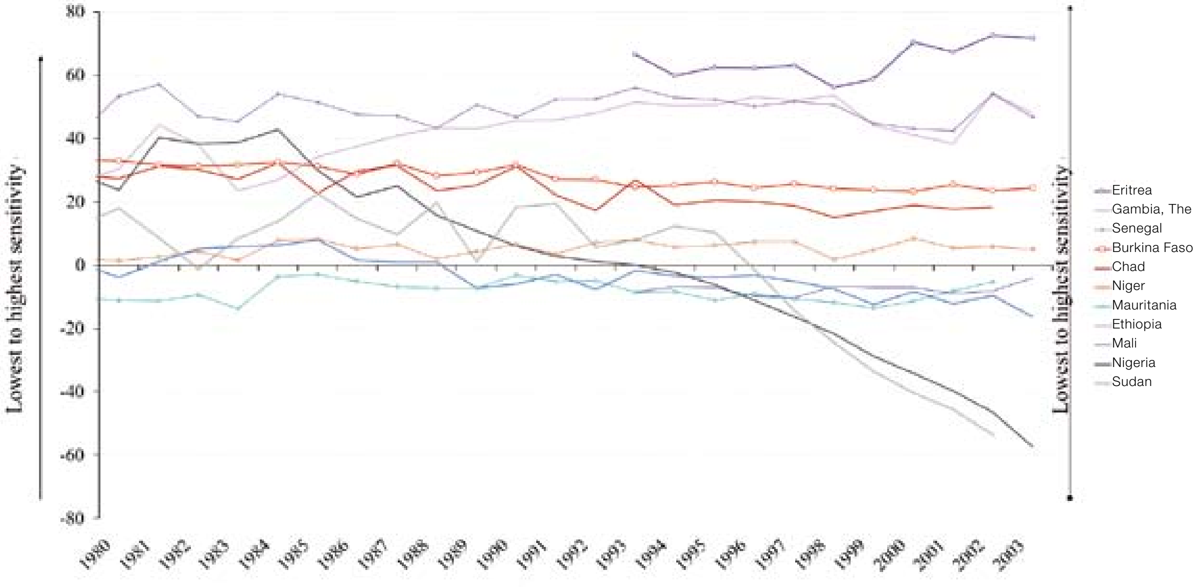

Figure 2

Evolution of the sensitivity of agricultural production growth to rainfall

These results have nevertheless to be interpreted with care, in particular, estimated absolute levels of sensitivity should not be interpreted on their own. The estimation technique produces unstable values for these sensitivities, depending on the selected interval of estimation, or the number of countries used for the regression. Furthermore, the estimation above indicates that in 2004, in Sudan and Nigeria agricultural production growth was negatively related to rainfall deviation. It is the use of interaction terms that induce sensitivity to go below zero in these two countries, but it should not be interpreted as an inverted relationship between rainfall and agricultural growth.

5.1.2 Effect of rainfall deviation on urbanisation growth

The best specification suggests that urbanisation growth (URB) is sensitive to rainfall deviations (RAIN). This sensitivity depends furthermore on the variation of rural density (DENS) and an indicator of income gap (GAP) measured here as the difference between GDP per capita and agricultural added-value per worker. To control for different stages of development between countries share of urbans in total population (USHAR), log of total population (POP), and income gap (GAP) are used. The following equation used lagged values for explanatory variables, as it proves to give more robust results and suggests that the decision to move to urban areas takes time after a rainfall shock.

$$URB = 0.91 + RAIN \times (-1.22 - 0.17GAP + 0.04DENS) + 0.1POP + 0.03GAP - 0.03USHAR$$

(all explanatory variables in -1 lag)

As for the agricultural production channel equation, all coefficients are statistically significant at the 10% level and signs of the coefficient are in line with intuition (see table A2 in annex). The explanatory power of these variables in explaining urbanisation growth is nevertheless lower than in the agriculture channel equation, 18% against 24% before (see infra). Urbanisation sensitivity to rainfall appears also to be far less important than agricultural production: all things equal, a deviation of -0.1 of rainfall from its mean leads to an increase of urbanisation growth of 0.12%. This sensitivity increases slightly when considering income gap, as a higher income gap incites more people to leave rural areas when faced with difficult conditions. The equation also suggests that an increase in the rural density leads to a small decrease of the sensitivity of urbanisation to rainfall. The statistical role of this variable is minor but significant. This result, counterintuitive to scarcity and resource pressure interpretations, might reflect that an increasing rural density is a signal of a more productive agricultural sector. High rural densities are observed in "peri-urban" areas with better marketing conditions, on fertile soils, in areas with up-graded production extension infrastructure, etc., softening thereby the sensitivity to climatic conditions and reducing the income gap.

Figure 3 presents the evolution of sensitivity of urbanisation growth to rainfall across countries, as suggested by the estimated equation. These sensitivities do not show any trends and have been rather flat in all countries during the period of estimation. Furthermore, these sensitivities in levels are very close between countries, which was not the case in the agricultural channel, and does not produce a meaningful ranking. Note, that the problem of sign inconsistency of sensitivities remains even if it appears far less severe than in the agricultural channel.

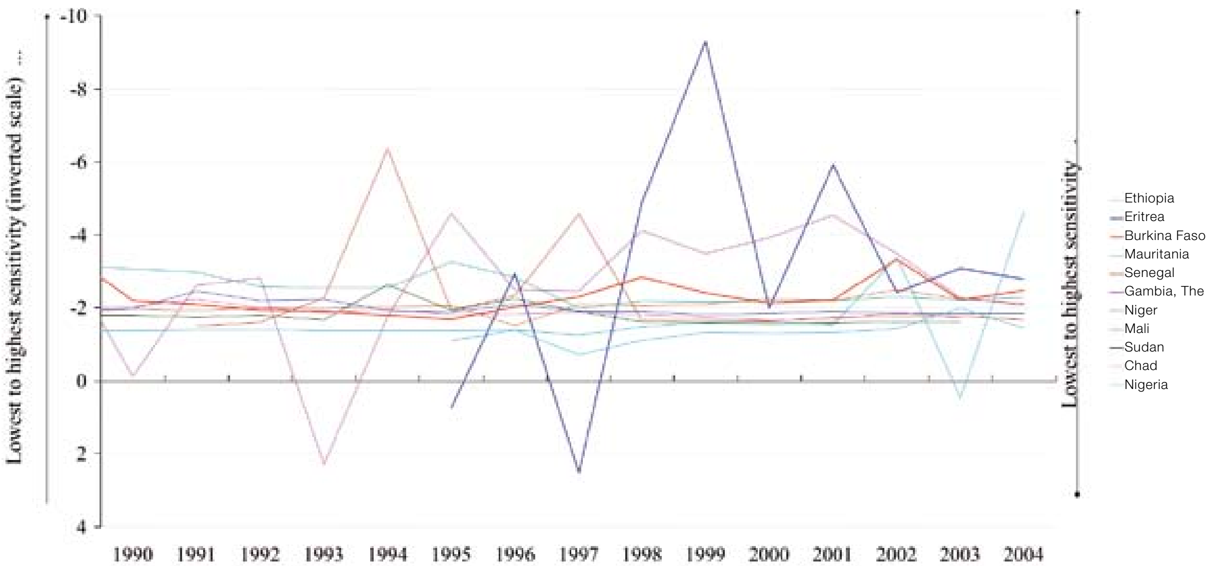

Figure 3

Evolution of the sensitivity of urbanisation growth to rainfall

5.2 Stage 2 of estimation: Role of climate as a trigger of security events

As an estimation of "consequences of consequences", stage 2 uses the results from the two channels previously investigated and tries to relate them to security issues. Specifically, the part of agricultural production and the part of urbanisation growth explained by rainfall deviations. Both are used as variables proxying climate trigger effects on security events. An indicator variable of drought is included as a supplementary climate trigger, assuming that extreme events have further increased the trigger effect of climate changes on security.

The estimated equation is complemented with socio-economic variables, controlling for differences between countries and capturing non-climatic conditions assumed to affect security vulnerabilities of a country. Table A3 in the annex presents the results. Given the estimation procedure, this relationship describes how the evolution of these variables has led in the past to a security event, but it does not produce an actual estimated probability to observe a security event[9].

All variables appear to be significant at the 5% level, with estimated coefficient signs in line with intuition, with the exception of the drought indicator and the log of population growth which are both rejected by the data. The model explains poorly the past occurrence of security events, with an R^2 of only 9%.

Results on climate trigger effects suggest that rainfall deviations, through its effect on agricultural and urbanisation growth, explain the occurrence of security events observed two years later, while the drought indicator appears not to be significant. Estimated coefficients are however low: -0.014 for the part of agricultural production growth explained by rainfall and 0.022 for the part of urbanisation growth explain by rainfall. However, to obtain the overall sensitivity of security to rainfall deviations for each channel, these coefficients must be multiplied by the sensitivities to rainfall deviation estimated in stage 1. This shows the predominance of agricultural production over urbanisation growth as a channel through which rainfall triggers security events: assuming other sensitivity variables at zero for simplicity, the overall sensitivity of security to rainfall deviation is - 0.36 for the agriculture channel against - 0.03 for the urbanisation channel[10]. This very low sensitivity of the urbanisation channel confirmed the idea that even in the short-term, additional arrival of rural populations in cities is not creating security instabilities.

Looking at the set of socio-economic variables, most coefficient estimates are in line with other studies. Suggesting that SSA countries with highest GDP per capita are less prone to observe a security event, and that high trade openness is limiting the occurrence of security events. Higher political stability goes the same way in our estimated model. However, education appears as increasing probability for security events occurring, while the literature has often documented evidence of a hyperbolic relationship between education and conflict (see Collier and Hoeffer). We seem therefore to only capture one part of this hyperbolic relationship, where higher educated people are more prone to understand state errors and to exert counter-power influences, while we fail to capture that very low educated people are also more prone to conflict. Finally, a less common variable is used, showing some interesting results: higher levels of aid per capita are associated with higher probabilities for security events occurring.

Given values in 2004 of these socio-economic variables and of rainfall deviations from its mean, figure 4 shows security vulnerabilities for each country in 2004 based on the previous results:

9 This relates to the two-stage least square estimation procedure choosen here: this estimation can deal with the dichotomous dependent variable, but the overall value of the estimated dependent variable is not constrianed between 0 and 1. Probit models are used to infer actual probability.

10 For example in the agricultural growth channel, we set ***a priori*** the percentage of irrigated land and added value per worker to zero, which implies a sensitivity of agricultural growth to rainfall of 26.8. Multiplying it with the sensitivity of the security issue to this channel results, -0.014, leads to an overall estimated sensitivity of security to rainfall of -0.36.

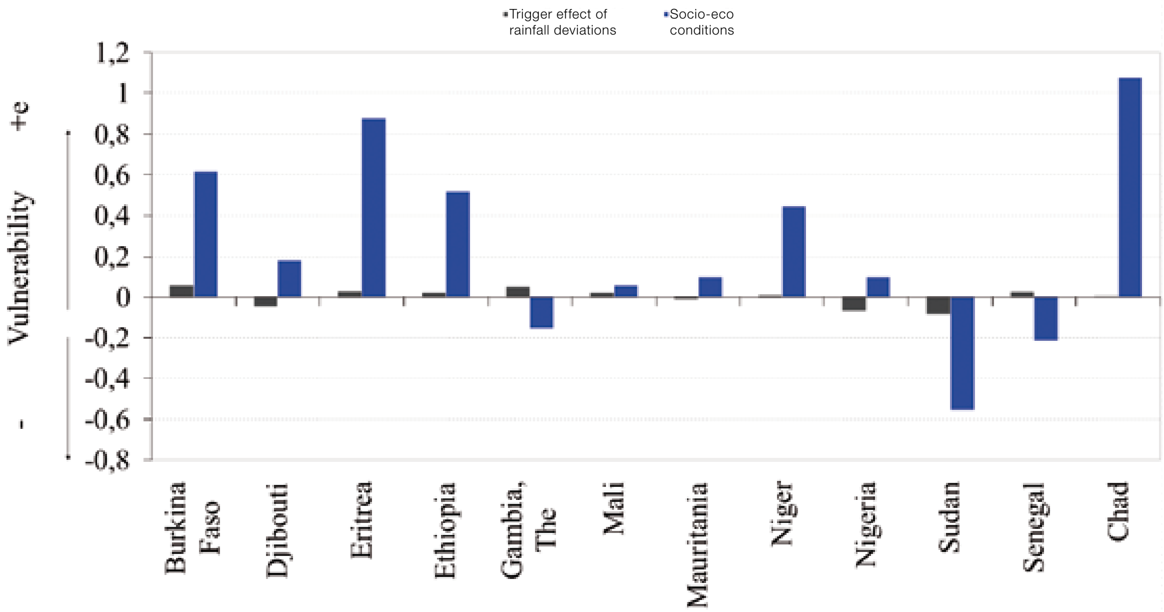

Figure 4

Security vulnerabilities in each country in 2004

Figure 4 suggests that, whatever the country, security vulnerabilities appear to be largely determined by socio-economic conditions, while rainfall has a smaller relative effect. However, it should be kept in mind that socio-economic conditions used in this specification are low-variance long-term trends, and relate more to structural vulnerabilities. Rainfall deviations, on the contrary, are short-term with high variance, and are more prone to trigger a conflict when structural long term vulnerabilities are already at a high level.

Figure 4 also highlights some major drawbacks of this model. Inside the set of climate trigger effect variables, the dominance of the agricultural channel implies that the inconsistency in levels of sensitivity of agriculture to rainfall in Sudan and Nigeria is reproduced in the overall climate trigger effect: in 2004, rainfall deviations were negative and below mean in Sudan and Nigeria, respectively at -0.2 and -0.4, which should have theoretically increased security vulnerabilities, while our specification suggests that it lowers security vulnerability in these two countries.

5.3 Using model outputs for vulnerability mapping

An initial series of maps that could be produced relate to the set of socio-economic variables used to infer baseline conditions of security vulnerabilities in each country. The estimated coefficients can be used as weights in producing vulnerability maps related to socio-economic conditions. The ranking produced would be more or less equivalent to what is suggested in Figure 4 where Chad and Eritrea appear to have the worst socio-economic conditions of the Sahel band regarding security vulnerability, while Senegal and Sudan are at the opposite. Note, the sensitivity for Sudan is strongly influenced by a very important increase in its GDP per capita during the last decade (due to a large increase in oil revenues), probably biasing the very low security vulnerability of Sudan with regard to its socio-economic conditions.

However, given the earlier discussed insufficiencies of quantitative models, the interpretation of the other estimations has to be careful:

- Looking at country-sensitivities of agricultural production growth to rainfall, it could have been interesting to illustrate on a 2-layer map the 2 variables that we found which have an influence on the sensitivity of agriculture to rainfall (% or irrigated land and agricultural value added per worker). However, using estimated coefficients as weights would result in a very strong contribution of agricultural added-value per worker on sensitivity while percentage of irrigated land would have a very low contribution.
- In the same vein, all variables that have been found to affect the size of the trigger effect of rainfall deviations on security could be used to construct a vulnerability index. However, when aggregating the index based on estimated coefficients, the weights have to account for the large influence of the agricultural value-added per worker variable (due to the dominance of agricultural production channel over urbanisation, and dominance of added-value per worker in agriculture channel).

6 Conclusion

As with previous modelling attempts, explanatory power of the presented specification is very low, and the absolute levels of estimated coefficients prove to be unstable during the period of estimation. An investigation of the role of interaction terms, commonly used in the empirical literature as a tool to capture non-linearity, has been made by checking for consistency in resulting country-varying estimated sensitivities. It revealed serious inconsistencies in the estimated results, and provides some evidence of the dubious validity of interaction terms as a form of non-linearity.

The model has confirmed statistical evidence of the role of climate variability in triggering conflict. It also argues that it is rather through its effect on GDP growth that climate is triggering conflict, while urbanisation growth has proved to be an insignificant channel of transmission. However, inconsistencies in some estimated coefficients and predominance of one variable in assessing factors determining sensitivity of security to rainfall limit the interpretative power. Model outputs can still be utilised to produce vulnerability maps based on socio-economic conditions, but results should to be assessed in a qualitative way.

For future research, the use of other time-series variables assuming to affect sensitivities of channels to rainfall, and the use of other non-linearity forms might produce more consistent estimations.

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Annex

Table A1

Results from the first stage, agricultural production growth / rainfall

Variable	Coefficient	Std. Error
Rainfall	26.75***	6.28
Rainfall * % irrigated land	-0.85*	0.46
Rainfall * value added per worker	-0.06***	0.02
Growth of livestock production	0.23***	0.08
Growth of crop production	0.19***	0.03
c	3.47***	0.84
R^2 aj	0.24	

Sources: WDI, FAO, UK Met Office Hadley Centre / Notes: first-stage of a two-stage least square, corrected for variance across country with PCSE / ***,**,* indicates respectively significance of estimated coefficient at the 1%, 5% and 10% level

Table A2

Results from the first stage, urbanisation growth / rainfall

Variable (lag)	Coefficient	Std. Error
Rainfall (-1)	-1.22***	0.38
Rainfall(-1) * Variation in rural density (-1)	0.04**	0.02
Rainfall(-1) * Income gap(-1)	-0.17*	0.10
Population total (log) (-1)	0.08**	0.04
Income gap(-1)	0.03***	0.01
Urban population share (-1)	-0.03***	0.00
c	0.91	0.77
R^2 aj	0.18	

Sources: WDI, FAO, UK Met Office Hadley Centre / Notes: first-stage of a two-stage least square, corrected for variance across country with PCSE / ***,**,* indicates respectively significance of estimated coefficient at the 1%, 5% and 10% level

Table A3

Results from the second stage, channels to security indicator

Variable	Coefficient	Std. Error
Drought event	0.02	0.0138
Agri channel (-2)	-0.014***	0.0039
Urb channel (-2)	0.022*	0.0124
Population total (-2) log	0.005	0.0126
Aid per cap (-2) log	0.024**	0.0112
GDP per cap (-2) log	-0.129**	0.0562
Literacy rate (constant)	0.002***	0.0007
Trade openness (-2)	-0.001*	0.0005
Stab politique (Polity IV)	-0.002*	0.0008
c	0.690	0.5608
R^2 aj	0.09	

Sources: WDI, FAO, UK Met Office Hadley Centre, Polity IV database, EM-DAT database / Notes: first-stage of a two-stage least square, corrected for variance across country with PCSE / ***,**,* indicates respectively significance of estimated coefficient at the 1%, 5% and 10% level

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