Simulating Territorial Integrity and Dis-integrity of States Ⅰ: Integrative Application of MAS and GIS

SAKAMOTO Takuto[1]

Introduction

Maintaining exclusive rule over the recognized territory is one of the first tests a government of a sovereign state must pass in order to establish its empirical existence. In some countries, however, it remains a remote goal to attain, mainly due to internal armed conflict or for other reasons. In fact, the reality shows great diversity in this aspect of sovereign statehood. While for many countries unified rule under a single government seems too natural to be seriously questioned, for others prolonged territorial division between the government and its contender has been a dominant feature during most of their existence. Still others, at one time or another, suffered from total disappearance of any form of effective governance due to extreme disintegration of territorial rule.

This paper reports an ongoing research project for grasping such diversity. One of its major aims is to construct a model which can reproduce the diverse spatial patterns of integration and disintegration of territorial rule having been observed in various countries. Such a model hopefully helps us understand and explain the phenomena in a comparative manner. Utilizing two developing methods—multi-agent simulation (MAS) and geographical information system (GIS) —in an integrative way, the model takes the form of a "virtual state" in a computer, where a large number of virtual inhabitants and organizations (government and insurgent organizations) interact with each other in settings sufficiently close to those in the corresponding "real state". In the following sections, this model will be described with some illustrative examples of its empirical application to the countries in the Horn of Africa.

1. Background

Space enters naturally into any analysis of territorial rule. It is obvious that sovereign states are spatially demarcated entities where rule, whatever its content, has some spatial properties (e.g. expansion/recession). It should be noted, however, that the process which causes dynamics of integration and disintegration of territorial rule, i.e. competition between the government and insurgent organization(s), is in itself strongly conditioned by a territorial makeup of the country in question. As some case studies of domestic armed conflicts in the Horn of Africa make clear (see

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[1] Research Fellow, the Graduate School of Arts and Sciences, the University of Tokyo

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for example Young 1997; Johnson 2003), substantial part of this process is local in the sense that what drives integration/disintegration of the country at large is micro-level interactions that spread from one locality to another. In each locality, fierce competition among competing organizations occurs involving many inhabitants living there and its outcome largely depends on the "grassroots" conditions of the locality concerned, such as political orientation of the inhabitants and their socio-cultural composition, all of which are variable across the territory.

These points are a theoretical bottleneck as well as empirical characteristics, because it is not easy to formulate locally conditioned interactions among a large number of diverse actors over space. In fact there is hardly any theory that explicitly incorporates and formalizes such a spatial dimension of rule in the relevant literature (for a notable exception, see Doreian and Hummon 1976: Chap. 7). The growing literature dealing with "collapsed"/"failed" states (e.g. Zartman 1995; Rotberg 2003; Miliken 2003; Chesterman et al. 2005), where various aspects of recession and deterioration of state control have been discussed, has suffered from a general paucity of theories and models, in contrast to a confusing abundance of descriptive labels. Apart from a few analyses (e.g. Herbst 2000), it lacks vigorous theoretical treatment of any of these aspects. In the theoretically vigorous literature of civil war (e.g. Posen 1993; Walter 1997; Fearon 2004), on the other hand, formalizing spatially conditioned interactions found in armed conflicts mostly remains out of its subject of theoretical concern, although a few interesting attempts to bridge this gap, employing the methods to be taken up below, were recently reported (e.g. Cederman and Girardin 2006).

Fortunately, recent years have also seen some encouraging methodological developments, which provide an opportunity to overcome the above-mentioned bottleneck, thus enlarging feasibility of explicit theoretical treatment of territorial rule. Gradual spread of MAS, especially its spatial version, into the field of social modeling is one of such developments. Already in political science, several researchers have tried to apply this technique to analysis of such diverse phenomena as war, identity formation and secessionism, modeling interactions among many "agents" on abstractly composed virtual space (e.g. Cederman 1997; Lustick et al. 2004; Rousseau and van der Veen 2005).

To the extent that they are explicit about formalizing more or less local interactions among spatially arranged agents, these models perfectly fit the theoretical interests mentioned above. At the same time, however, these works are insufficient in terms of empirical relevance, being content with deriving some heuristically interesting observations from computer simulations; for example, the stronger the government, the more inclusive identity will the inhabitants uphold (Cederman 1997: Chap.8). While these observations may contain a certain amount of truism, it is not so clear that they would be tenable in other settings, in particular, empirically more realistic settings than the abstract ones where their simulations were conducted. In general, macro-properties which emerge from locally bounded micro-level behaviors show strong dependence on specific spatial configuration.

In this context, another recent development in methodology could be helpful. It can be seen in the growing industry of GIS, which provides integrative platform for constructing, processing and analyzing various kinds of spatial data such as human distribution over the globe. This technique has been actively applied in many fields including political science (Herbst 2000; Berry and Baybeck 2005), and it would be quite natural to combine this computer based method with another one, MAS, in order to make the latter more empirically based (see Gimblet 2002). From a methodological point of view, what follows is one example of fruitful contributions the integration of methods, i.e. that of MAS and GIS, could make to social sciences.

2. The MAS Model

The model generates diverse dynamics of integration/disintegration of territorial rule in a virtual state constructed in a computer. Its territory is represented by a two-dimensional space, over which many virtual inhabitants are distributed. The inhabitants are differentiated from each other according to several social/cultural traits (ethnicity, religion, etc.), and all of them are under rule of a government at the start. In addition to the inhabitants and the government, the model assumes existence of a large number of latent organizations which are trying to infiltrate the country and subvert the rule of the government. Given such a situation, the model dynamically determines which of the competing organizations governs each part of the territory and inhabitants on it at each time, according to the stochastic rules described below.

2.1 Agents

In order to formalize the above setting, the following two kinds of agents were designed.

(1) *Population Cell* (*PopCell*) :

The model imposes grid structure on a territory of a given state, and this agent represents each piece of the territory thus demarcated with inhabitants living on it. In the simulations below, the territory of each virtual state was gridded at a rather crude resolution of 30 arc-minutes (approximately 55km at the equator). *PopCell* is characterized by the following three variables.

State: specifies which of the competing organizations governs the concerned cell.

Traits: describe socio-cultural traits of the inhabitants on the cell. Following Axelrod (1997: Chap.7) and Cederman (1997: Chap.8), the model represents these traits as a vector of strings such that a vector ("02", "93", "02") denotes, for example, those who are Tigrinya speakers ("02"), religiously Christians ("93"), and regionally Eritreans ("02").

Resources: denotes the amount of human and material resources the cell has. Its value is assigned using the population distribution and GNI per capita data of each country.

Of these variables, only the first is a time-variant endogenous variable, while the others are assumed to be time-invariant, their values being given from the GIS data of the corresponding "real state" in the way that will be shown later. Macro-dynamics of integration/disintegration of territorial rule in a virtual state is generated by time-series changes in overall configuration of *States* of *PopCell*s across its territory.

(2) Ruler

It represents ruling entities including the government and insurgent organizations, the former defined as the *Ruler* that holds the capital of a virtual state. Its main function is to forcibly exclude other *Ruler*s, and thus expand and preserve exclusive rule over the territory. For this purpose, it mobilizes human and material resources of the *PopCell*s under its rule and spatially allocates—deploys—them to each cell according to the formula described in the next section.

One of its defining characteristics is specified by its *Traits*, which stipulate its inclination toward inhabitants in terms of their socio-cultural traits. This variable is also represented in a vector form and, following Cederman (1997: Chap.8), can take a value indicating some sort of political "wildcard", that is, indifference toward the inhabitant's traits; for example, a vector ("02","**","02") describes a *Ruler* which is ethno-linguistically and regionally committed to Tigrinyans ("02" in the first element) and Eritreans ("02" in the last) respectively, while religiously neutral (denoted as "**"). As to the *Ruler* which is the government at the start of simulation (*Initial Government*), these values are exogenously determined based on crude empirical characterization of the corresponding government in reality. Otherwise, they are randomly generated for each *Ruler* at the beginning and held constant thereafter.

In addition to the *Traits*, it has several variables concerning its mobilization capacity, the details of which will be introduced below.

2.2 Behavior of the Agents

The simulation proceeds in the schedule as illustrated in Fig.2. It is run for the given number of "periods", each of which has the "deployment phase" and the "state transition phase". In the former phase, *Ruler*s mobilize resources from the *PopCell*s then under its rule and deploy them over their respective territories. In the latter phase, which in itself consists of the specified duration of sampling interval, *State* configuration of the *PopCell*s over the territory is to be incrementally changed, according to the stochastic logic based on local interactions of each cell in its neighborhood. Specifically, the following behavioral rules are to be applied to each phase.

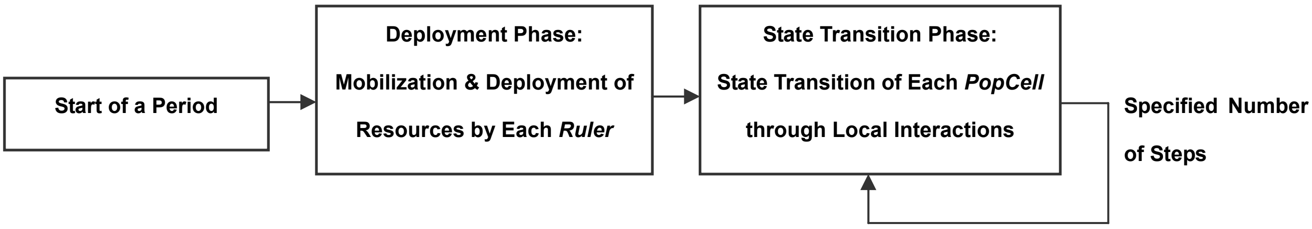

Fig.2 Simulation Flow during One Period of Interactions

(1) Deployment Phase

Each *Ruler* is in competition with other *Ruler*s, latent as well as present ones. Latent *Rulers*, which have not acquired any piece of the territory, are trying to infiltrate a virtual state from a randomly determined unknown point on the territory. This means that threat to each present *Ruler* is omnipresent in the sense that its enemies can emerge anywhere in its zone of control, requiring it to spread its mobilized resources, and thus make its presence felt, across space.

In the model, this resource deployment by *Ruler*s is formalized as formation of a certain kind of "field" defined over the territory. To begin with, let $R_t(k)$ denote the amount of gross resources which a *Ruler* k mobilizes from the *PopCell*s under its rule at the beginning of time period t. Assuming linearity, then

$$R_t(k) = a_k \sum_{i \in \Lambda_{t,k}} \rho(i) + b_k \qquad \ldots \text{(a)}$$

where $\Lambda_{t,k}$ is a set of *PopCell*s which are ruled by a *Ruler* k at the start of the period t, and $\rho(i)$ is the *Resources* of a *PopCell* i while a_k and b_k are non-negative constants controlling each k's mobilization capacity. To make things easier to deal with, in the simulations reported below, it was assumed that every *Ruler* mobilizes resources from *PopCell*s at the same level. Without losing generality, this assumption allows a_k to be set to 1.0 for all k. As to b_k, which specifies the amount of externally generated resources available to k, the simulations were limited to simplified situations where these external resources, the amount of which was parameterized, accrue only to the *Ruler* holding the capital, i.e. the government.

Using the above defined Mobilization Function $R_t(k)$, then, a Deployment Field $D_t(i, k)$ for each *Ruler* k in each period t can be formulated as

$$D_t(i,k) = w_t(i,k) R_t(k) \quad (i \in \Lambda_{t,k})$$
$$D_t(i,k) = 0 \quad (i \notin \Lambda_{t,k}) \quad \ldots \text{(b)}$$

where $w_t(i,k)$ denotes normalized weight a *Ruler* k attaches to a *PopCell* i in its allocation of resources to each cell under its control. Although various ways of specifying its concrete form could be imagined, here, in a rather expedient manner, the following specification is employed.

$$w_t(i,k) = \frac{\log(\rho(i))}{\sum_{j \in \Lambda_{t,k}} \log(\rho(j))} \quad (i \in \Lambda_{t,k}) \ \ldots \text{(c)}$$

That is, importance of a *PopCell* to a *Ruler* in the latter's decision concerning resource deployment depends only on a *scale* of the amount of resources the former is able to provide.

(2) State Transition Phase

Given a set of *Ruler*s that have various political inclinations represented by their *Traits* and situated in a Deployment Field D_t they formed at the beginning of each time period, each *PopCell* is changing its *State*, i.e. the *Ruler* to which it belongs, thus causing macro-dynamics of territorial integration/disintegration. Reflecting the observations noted in section 2, the process which governs this dynamics is locally defined, and consists of two kinds of interactions: "loyalty or exit" of inhabitants on *PopCell*s and "coercion" exercised by *Ruler*s. The former is inhabitants' "freewill" political choice between locally competing *Ruler*s, leading the concerned *PopCell*'s *State* to one place where the most preferred *Ruler*, in terms of affinity between the *Traits* of two kinds of agents, tends to dominate. The latter is military competition among *Ruler*s targeting at a *PopCell*, leading the latter's *State* to another place where the locally superior *Ruler*, in terms of the amount of resources deployed in the neighborhood, tends to prevail on the cell. This intersection of interactions with often conflicting directions is at the core of dynamics of the model.

As to formalization, the model represents these interactions in a somewhat indirect way, borrowing ideas from a spatial modeling technique extensively employed in statistical mechanics and other fields of sciences because of its theoretical flexibility[2]. Using a locally defined potential function, which incorporates the logics of the interactions, and a certain form of probability distribution, both defined over all possible *States* a *PopCell* can take, it calculates probability of the cell being under rule of each *Ruler* given local conditions at each time. Transition to the next *State* occurs according to the probability thus yielded.

Specifically, for each *PopCell* i and for each *Ruler* k, potential, represented as H below, for i's

[2] Now classical [Liggett 1985] provides comprehensive theoretical background of such modeling. For computational treatment of these spatial models, see [Iba et al. 2006].

State changing from k is yielded in the following three ways according to relationship between the two agents. The first case is that k is 'present' in i's neighborhood in the sense that k's deployed resources $D_t(j, k)$ is non-zero on at least one *PopCell* j in the neighborhood. Suppose that $V(i)$ is i's von Neumann neighborhood, $X(i) = V(i) \setminus \{i\}$, and $Q(i)$ is a set of *Ruler*s that are present on $V(i)$. Let also $\omega(j)$ denote *State* of a *PopCell* j and ω_X its configuration on a set X. Then, for each i and for each k, given a Deployment Field D_t and a local state configuration ω_X,

$$\mathrm{H}_{\{i\},\omega_X}^{D_t}(k) = -Aff(i,k) - c \cdot \sum_{j \in V} \delta_{\varpi(j),k} D_t(j,k) \quad (k \in Q(i)) \qquad \text{... (d)}$$

where δ is the Kronecker's delta which takes 1 if $\omega(j)$ = k and 0 otherwise. The first term on the right hand describes potential brought about by evaluation of a *Ruler* k by inhabitants on i, which exclusively depends on the function *Aff*. This function specifies affinity between the *Traits* of the concerned two agents just the same way as Cederman defined his "fit" value between a communal identity and a transcommunal identity (see Cederman 1997: p.192), except that its value is normalized here on [0, 1]. That is, *Aff* = 1.0 means total commitment of k to i in terms of all the relevant socio-cultural categories, while, if its value is 0, there is no common ground between the two agents, causing total alienation of i under k's rule. The second term, on the other hand, specifies potential of military coercion exercised by k. Its "weight" consists of the amount of resources deployed by, and accessible to, k in i's Neumann neighborhood, which reflects, in a much simplified way, the obvious fact that resources any organization can commit to invasion or defense of territory has some spatial limitations at any given time.

Lastly, c, which is to be called the "Coercion Effect" below, is a non-negative parameter scaling the potential of the second interaction in relation to the first. In other words, this parameter controls relative importance of the two kinds of interactions in determination of *State*s of *PopCell*s. If $c \rightarrow 0$, things become reduced to a kind of "popularity voting" where only preferences of the inhabitants concerning *Ruler*s matter. If $c \rightarrow \infty$, in contrast, everything would be dependent on the might of the strongest irrespective of the inhabitants' political wills. In general, if c is set to a relatively small value, it becomes "inherently" more difficult for *any* *Ruler* to rule *any* virtual state because the same amount of resources can make less effect.

If k is a latent *Ruler* which has not emerged on the territory yet, somewhat different treatment is required. Suppose $L(i)$ denotes a set of *Ruler*s whose randomly determined points of infiltration are on a *PopCell* i. Considering d as the exogenously given amount of resources representing "initial boosts" to latent *Ruler*s[3], then

$$\mathrm{H}_{\{i\},\omega_X}^{D_t}(k) = -Aff(i,k) - c \cdot d \quad (k \in L(i))$$

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[3] Although difference in this parameter did make some impacts on simulation results, it was also true that these impacts had a ceiling beyond a certain small value of d because of its temporary character as an input to a *Ruler*.

Otherwise,

$$\mathrm{H}_{\{i\},\omega_X}^{D_t}(k) = 0 \quad (k \notin Q(i), k \notin L(i))$$

Using the thus defined local potential function, given a field D_t and a local state configuration ω_X, conditional probability of a *PopCell* i being under rule of a *Ruler* k is generated as follows.

$$P_{\{i\},\omega_X}^{\varepsilon,D_t}(k) = \frac{1}{Z_{\{i\},\omega_X}^{\varepsilon,D_t}} \exp\left(-\varepsilon^{-1}\mathrm{H}_{\{i\},\omega_X}^{D_t}(k)\right)$$
$$Z_{\{i\},\omega_X}^{\varepsilon,D_t} = \sum_{l \in \Psi} \exp\left(-\varepsilon^{-1}\mathrm{H}_{\{i\},\omega_X}^{D_t}(l)\right)$$

where Ψ is a set of all the possible *State*s a *PopCell* can assume and ε controls the amount of stochastic noise. This form of probability distribution—the Gibbs distribution—has its basis in information theory. Although there is no space to detail the procedure of its derivation (see for example, Kuroda and Higuchi 2006: Chap.1), it suffices here to say that this distribution, while leading a *PopCell* into *State*s with lower potential in accordance with the interactions depicted above, allows, among all the possible probability distributions on Ψ, the maximum number of contingent state transitions at the given amount of noise specified by ε.

Formally speaking, the purpose of the state transition phase in the model is to obtain sufficiently "probable", i.e. stationary, state configurations of *PopCell*s in each time period t during which their environments such as a Deployment Field D_t are fixed and external to their interactions. For this purpose, in simulation, each *PopCell* changes its *State* in the specified number of sampling steps. In each "Monte Carlo Step (MCS)", the cells across the territory are selected in a randomly generated order[4], and update their respective *State*s according to the stochastic rules described above. The simulation proceeds to the next time period when its deployment phase begins upon receiving feedbacks from a state configuration after the last MCS of the previous period.

3. The GIS Data

The major thrust of this research project is, as indicated in section 2, to simulate diverse dynamics of territorial rule in sufficiently realistic virtual states. This can be attained by running the above defined MAS model in empirically based spatial settings. Here, utilizing various data processing procedures GIS provides (e.g. rastering, resampling, spatial interpolation, etc.), these settings are constructed from the following two kinds of spatial databases.

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4 A selection order is not a critical element in simulation of the model. Other ways of ordering agents, for example a predetermined lexical order, are at least theoretically guaranteed to generate the same stationary distribution of state configurations.

(1) Population Distribution

Every country has its own spatial configuration of human and material resources. In the simulations conducted here, such a configuration was crudely approximated by population distribution over territory of a country, which was to be weighted, for the purpose of inter-state comparison, with GNI per capita data of the country in question. *Resources* variable of each *PopCell* was thus determined by setting its value to the product of the total number of people living on the corresponding patch of the territory (at a resolution of 30 arc-minutes) and annual GNI per capita of the country in an appropriate year.

As to sources of the data, several products of world-wide spatial population data are now available online. Among them, this project employed the *Gridded Population of the World* (GPW) for the clarity and simplicity of its mapping method (CIESIN et al. 2004)[5]. This GIS data set disaggregates, in a somewhat crude manner, estimated world population in 1990 and allocates them to a series of geo-referenced grids at a resolution of 2.5 arc-minutes. Fig.3-1 depicts the estimated 1990 population distributions of Ethiopia (before the independence of Eritrea) and the Sudan. Annual GNI per capita of each country in the same year ($170 for Ethiopia, $130 for Somalia, $580 for the Sudan) was acquired from the World Bank's *African Development Indicators* (World Bank 2005).

(2) Traits Distribution

So far, extensive application of the GIS to the fields of social sciences has been hindered by a paucity of substantial data beyond those concerning human demography. In fact, there have been no comprehensive GIS data sets mapping socio-cultural traits which characterize human beings over the globe, although a large scale project dealing with world-wide distribution of ethnic groups has now been under way (see Cederman et al. 2006). Because of such a situation, empirical spatial data in these respects had to be collected from various non-digital data sources including paper maps, and integrated in digitized forms on a GIS platform. *Traits* variables of *PopCell*s were given values using the thus constructed GIS databases.

Focusing on the countries in the Horn of Africa (Ethiopia-Eritrea, Somalia and the Sudan) which will be taken up below as the cases for simulations, the following three categories of traits have been conspicuous for their political and social importance in these countries: ethnicity, religion, and region. Construction of the spatial database regarding the former, for example, owed much to existing ethno-linguistic distribution maps such as the comprehensive linguistic maps found in *Atlas of the World's Languages* (Asher and Moseley 1993), as well as the relevant encyclopedias and dictionaries, which were consulted in examining and adjusting classification

[5] As of January 2006, this data set is accessible at http://sedac.ciesin.columbia.edu/gpw.

of ethnic groups (e.g. Skutsch 2004). Fig.3-2 illustrates examples of the ethno-linguistic maps formed in this way. Applying various GIS data processing methods to these data yields distributions of *Traits* of *PopCell*s in virtual states, as shown on Fig.3-3.

As to the third category of traits, which is supposed to capture regional divide (e.g. "North-South" division) often observed in the Horn countries, traits were approximated by classification based on administrative units in the colonial period[6]. In fact, what united linguistically and religiously diverse people as "Eritreans" in their long struggle against Ethiopia, for example, is nothing but the fact that they had been living on the space which belonged to the Italian colony of Eritrea in the past.

Sometimes, however, these categories are too broad to differentiate people and characterize various political inclinations of ruling entities. Indeed, in the Horn countries, narrower kin and/or territorial subgroups, such as those derived from the lineage structure of the Somali people, have not only had local and social importance, but also often had nation-wide political importance. In order to deal with these realities, the spatial data set of traits distribution has a few layers of additional information concerning sub-classes of each trait and incorporates as detailed information as possible based on multiple data sources, although there have not been almost any room for choosing these sources given a general shortage of spatial data at this level of human groupings[7]. Simulation in a virtual state can also be conducted using these lower categories. In this case, *Traits* of *PopCell*s are represented in an extended form such that a string "18-03-01" denotes inhabitants who belong to Ogadeni clan ("01") of Darod clan-family ("03") of Somali "nation" ("18"). *Traits* of *Rulers* and a functional form of calculating affinity between two *Traits* are extended accordingly.

4. Preliminary Simulations

How close can the reality be approached with the model and the data introduced above? The following is summaries of preliminary simulations conducted to answer this question.

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6 At present, the spatial data concerning colonial administrative units are crude, including only the largest units such as British Somaliland, Eritrea, the Sudan under the Anglo-Egyptian condominium, etc. and not including smaller ones like so-called "Closed Districts" in the southern part of the Sudan which have been one of few sources of "Southern identity" in that part of the country. Reflecting such paucity, simulations in the virtual Sudan were conducted in a rather unrealistic environment where regional traits of all the inhabitants are identical, although, as will be demonstrated, the results showed strong tendency toward some forms of North-South divide without differentiation of the inhabitants in this respect.

7 The data source of the Somali lineage groupings, for instance, dates back to the colonial period (see Lewis 1998).

4.1 Target Countries and Governments

Simulations were run in three virtual states which approximate the three relatively large states in the Horn, that is, Ethiopia before the Eritrean Independence, Somalia, and the Sudan. The government(s) in each country, according to which the Initial Government in the corresponding virtual state was given characterization, and the observed dynamics of territorial rule while it was in power, can be briefly described as follows.

Ethiopia: Haile Selassie ("03", "93", "01")

Imperial Ethiopia was unambiguous in its inclination toward Amhara-Orthodox centric "official culture" (e.g. Markakis 1990: Chap.4), which legitimizes the first two traits, "03" and "93", of the Initial Government in virtual Ethiopia. In terms of regional dimension of its characterization, which was represented as a crude dichotomous choice between Ethiopia ("01") and Eritrea ("02") in the model, its inclination was equally unambiguous, that is, alienating toward Eritreans.

Apart from sporadic small scale peasant rebellions, this government had faced threats to territorial integrity from several corners until it finally collapsed from the center in the 1974 revolution. The most conspicuous was the Eritrean insurrection since the early 1960s, although at this period it remained loosely organized rebellion mainly based on lowland Muslims and its infiltration into the highland was largely limited. The vastly stretched south and south-east region of the country, with its exposure to the Somali irredentism, had been another zone of endemic instability. While the government control in Ogaden had been maintained during most of its reign, its presence in Bale and Sidamo had been tenuous in face of the long-lasting upheaval in 1963-70 (see Gebru Tareke 1996).

Somalia: Siad Barre ("180302", "**", "01")

Political support base for the "socialist" regime of Siad Barre had experienced several changes in its extension, only to be reduced to a narrow circle of the President's cronies formed around his own Marehan clan ("180302") and a few others since the late 1970s (see Marakakis *op. cit.*; Lewis 2002: Chap.IX). Like the preceding regimes, his regime was largely southern-based ("01") in its regional inclination, alienating ex-British Somaliland inhabitants in the north-west.

The fate of the regime and its lasting impact on the country's territorial integration were well documented (e.g. Brons 2001: Chap.8). Starting from the north-west and north-east since the early 1980s, its control over the whole territory was rapidly deteriorated, leading to the total collapse of the country in the 1990s. Apart from self-declared Somaliland in the north-west and, to a lesser extent Puntland formed in the north-east, extreme disintegration of territorial rule among competing "warlords" has not been overcome to the present.

Sudan: Typical Northern Governments (“01”, “01, “01”)

With the early 1970s under the Nimeiry regime a somewhat exceptional period, the successive post-colonial governments in the Sudan have been more or less engaged in massive Arabization and Islamization of the whole country (see Marakakis *op. cit.*; Johnson 2003). Their unequivocal inclination toward Arab (“01”) and Islam (“01”) had been matched up with the equally consistent response, that is, endemic presence of various insurgents especially in the southern part of the country[8]. While in the first civil war from the early 1960s to 1972 control over this vastly stretched region fell into countless self-proclaimed “provisional governments”, the second civil war in 1983-2005 brought about a certain extent of unity among excluded peoples under the leadership of the Sudan People’s Liberation Army (SPLA), albeit often fragile one. Moreover, especially since the 1990s, other latent zones of instability in the north such as the Nuba Mountains, the north-east region and the Dar Fur have seen small scale armed rebellions, as the tragic upheaval in the latter attests.

4.2 Parametric Setting and Order Index

Except for the differentiating factors given above, i.e. the input data for and characterization of the government in each virtual state, the simulations in the three virtual states were conducted in the same parametric setting shown in Table 4 below.

Table.4 Common Parametric Setting for Simulations

The Number of Periods	200
The Number of Sampling MC Steps in Each Period	20
The Number of Rulers (including the Initial Government)	100
Mobilization Levels a_k	1.0 for all k
Exogenous Input Resources b_k	Variable on [0, 100] (if k is the Govt.) 0 (Otherwise)
Coercion Effect c	0.2
Initial Input to Latent Rulers d	1.0
The Amount of Stochastic Noise ε	0.1

The four kinds of parameters, a to d, were given values in consistency with a scale which defines the amount of human and material resources equivalent to 20 million dollars on an annual basis as one

8 As to specification of *Traits* of the Initial Government in the virtual Sudan, see Note 7 above.

unit of *Resources*. The value of Coercion Effect, 0.2, indicates a somewhat difficult environment for *Ruler*s in that they have to preserve and expand their respective zones of control in face of relatively large "popular pressures" exercised by the inhabitants on *PopCell*s. Although simulation results show substantial sensitivity to this parameter in a wider range, it was confirmed that a small amount of variation in its value made qualitatively little difference in characteristic spatial patterns of territorial rule in the three virtual states which will be reported below.

As to a variable which summarizes macro-behavior of virtual states, the following sort of entropy $I(\omega)$ was employed. Letting r_k denote proportion of total area of *PopCell*s under the rule of a *Ruler* k to the total area of the whole territory, it is defined as

$$I(\omega) = -\sum_{k \in \Psi} r_k \log_2 r_k$$

This aggregating index describes a given state configuration ω across the territory with the amount of information it has, in other words, with the degree of uncertainty concerning to which *Ruler* each *PopCell* belongs in the configuration ω. The base of the logarithm in the above expression set its scale such that $I(\omega)$ =0 denotes total unity under the rule of one *Ruler*, $I(\omega)$ =1.0 corresponds to configurations equivalent, in terms of the information amount, to equal division of territorial rule between two *Ruler*s, and so forth.

4.3 Results

Starting from the initial state where every *PopCell* is ruled by a single Initial Government, the simulations in the virtual states yielded diverse dynamics of territorial integration and disintegration. Some of them were realistic in the sense that obtained spatial configurations were consistent with the actual, and often apprehended (by the government in power), patterns of territorial division in the corresponding real states, albeit in a somewhat exaggerated fashion. The three panels in Fig.4-1 depict examples of such spatial configurations of *Ruler*s which were sampled after 200 periods of simulations. In this figure, the *PopCell*s colored red are those which remain under the rule of the Initial Government.

At the same time, however, the simulations generated other alternative scenarios due to the fact that the maximum amount of stochastic fluctuation is allowed in the model, requiring statistical treatment of the results. Fig.4-2 demonstrates the simulation results in each virtual state in the form of frequency distribution of $I(\omega)$ obtained after 200 time periods at a given level of the capital holder's advantage represented by b_k. Simulation was run ten times at each level of the advantage. In the figure, the zone colored red corresponds to situations in which the Initial Government somehow survived the whole periods and the blue-colored zone corresponds to those in which it disappeared from the scene. The lighter colors indicate more disintegrative territorial order. Note that grossly disintegrative order with the Initial Government's presence is hardly distinguishable from that without it, which justifies the order of the classes of $I(\omega)$ indicated on the right edge of each panel.

The following is brief descriptions of each virtual state's behavior drawn from these results.

Ethiopia: Haile Selassie

In the long run, the imperial government in virtual Ethiopia cannot avoid some form of rebellion in Eritrea in the north. Rebellions are almost certainly brought about by emergence of an ELF (the Eritrean Liberation Front)-like *Ruler*, whose *Traits* include an Islamic element ("01") attracting lowland Muslims and which often suffers from division along ethno-linguistic lines (e.g. Tigre vs. Afar) especially at lower levels of the government advantage. Although, in reality, the nucleus of the Eritrean People's Liberation Front (EPLF) which had many highland Christians in its leadership had already formed by the mid-1970s, substantial insurgent infiltration into the highland was not observed in most of the runs. As a result, without mobilization of the large Christian population, impressive spatial expansion of Eritrean insurrection had a certain limitation. In fact, there were only a few cases in which the provincial capital, Asmara, had fallen into the rebel's hands.

Moreover, at lower advantage levels, rebellions can be observed in other parts of the country as well. The regions where their occurrence was most concentrated are Ogaden and the Somali-inhabited part of Bale in the south-east, although, in reality, governmental control in the former had barely been maintained during the Haile Selassie's reign as described above. Other regions of frequent uprisings are Sidamo and the Afar-inhabited region of Danakil. What these regions have in common is a vast stretch of a single locally dominant ethnic group, which makes coordination and spatial expansion of insurgent activities relatively easy tasks. In contrast, other regions which also have similarly alienated peoples such as Muslim Oromos in the east and a large number of minorities in the south-west, in consistency with the reality, remained tranquil in most of the runs, for lack of such a spatial factor and/or for other reasons (e.g. "thick" presence of the government due to a large population of the concerned region).

Somalia: Siad Barre

As easily read from Fig.4-2, virtual Somalia under the Siad-Barre-like *Ruler* was prone to extreme disintegration of territorial rule and the government could not expect even its survival in the long run unless a substantial amount of external resources was available. The latter point is not unnatural given the fact that Somalia in reality had indeed been supported by an enormous quantity of resources accruing from oversea, which often amounted to nearly a half of its GDP (not government revenue!). The extreme fragility of its territorial integrity in comparison with the other two states can be explained by two factors. One is the general condition in this virtual state where any *Ruler* has to stretch its mobilized resources, a very small quantity in themselves, thinly over the vast territory. The other factor is the narrower extension of the Initial Government's strongholds, which promoted spontaneous emergence of major insurgent *Ruler*s in several regions.

As to "after the Siad Barre", the simulation results showed substantial variations including prolonged division of territorial rule among a large number of more or less narrowly based fiefdoms, while the prospects for reunification of the territory could not be supported from the simulations conducted here. At the same time, it should be noted, in many runs, there emerged relatively integrative ruling entities in the north-west region and the north-east corner of the Horn, corresponding to Somaliland and Puntland in reality respectively.

Sudan: Typical Northern Governments

As Fig.4-2 illustrates, the virtual Sudan under the specified Initial Government showed a strong tendency toward some form of north-south division, which was brought about by rebellions in the vast south where alienated inhabitants with diverse *Traits* are concentrated. On the other hand, aggregation of the results in the figure masks a certain extent of variation in this division. One typical pattern, which corresponds to those observed in the first civil war and during the early 1990s in the second, is characterized by "civil wars within the civil war", that is, serious territorial division among southern insurgent movements along ethno-linguistic lines. Another pattern, in contrast, captures a certain degree of unity attained by SPLA in the second civil war. The latter pattern became dominant at relatively higher levels of the government advantage, although a sufficiently strong government can easily contain insurgents anywhere and in any form. This is because of strength of a sort of "selection pressure" exercised on competing insurgent *Rulers*, which, in the context of the virtual Sudan, tended to choose a *Ruler* which could somehow attain integration of diverse inhabitants in the south and mobilize their resources accordingly.

Besides the south, at lower levels of its advantage, the government in the virtual Sudan tends to face emergence of insurgents, in this case exclusively ethno-centric ones, in the north-east region and the Dar Fur as well. Concerning another potential zone of instability in the real Sudan, the Nuba Mountains, on the other hand, occurrence of uprising was an extremely rare event in the virtual Sudan, probably due to the spatial configuration of *Traits* of *PopCell*s there in which alienated inhabitants (Nuba people) are scattered among core supporters of the government (Muslim Arabs).

5. Conclusions and Possible Extensions

Illustrative results gained from simulations in selective environments such as those shown above are not enough to draw empirical validity of the model presented here. To establish this requires much more simulations and much more extensive analyses, which are the subject of another forthcoming paper. It should be emphasized, however, that what have been described is more than a mere demonstration of plausibility of the model. In particular, with a few kinds of spatial input data concerning basic makeup of a state such as the population and socio-cultural composition, the model could generates diverse dynamics of territorial rule, some of which certainly "captured" the realities at least in an approximate manner. This is an encouraging development for the objective of this research project, that is, to construct a model which can reproduce the observed spatial patterns of integration and disintegration of territorial rule.

At the same time, the model also stimulates an imagination in regard to its various extensions because of its flexible form. For instance, the following extensions can be considered and implemented with a small amount of additional time and efforts.

(1) Toward More Responsive Agents

Ruler's behavior is largely conditioned by its weighting function $w_t(i,k)$ in expression (b). In the model depicted above, a *Ruler* deploys its resources in a rather unresponsive manner in that its way of weighting each *PopCell* under its rule, specified by expression (c), depends exclusively on the latter's *Resources* and does not reflect changing macro-circumstances of territorial rule in a direct way. By making the form of $w_t(i,k)$ slightly complex so that it is also dependent on other factors, for instance, whether the concerned cell is at the frontline vis-à-vis other *Rulers*, or whether it is situated in a "rebellious region", a more adaptable mode of behavior can be designed.

PopCell's behavior, described by potential function (d), also has many points of extensions. Especially the first term in the right hand of (d), which specifies evaluation of a *Ruler* by inhabitants on a cell, can be extended so that they differentiate *Ruler*s in terms of characteristics other than socio-cultural affinity. For example, if *Ruler*s' mobilization levels a_k in expression (a) are allowed to take different values, it becomes plausible that inhabitants tend to prefer a less exploitive *Ruler* in terms of a burden brought about by its mobilization. This requires some form of 'discontent term' to be included in (d).

(2) Conditions Beyond Boundary

As many other spatial simulations, some forms of fixed boundary conditions can be introduced to the model, thus enabling it to formalize various spatial influences coming across the state border. For instance, given a certain fixed configuration of *Ruler*s (e.g. governments in neighboring countries) with their own *Traits* around a territory of a virtual state, if the evaluation term of potential function (d) is made to depend on this boundary condition in case of the *PopCell*s adjacent to these oversea *Ruler*s, it may become possible to generate a sort of secessionism demanding unification with a 'homeland' country such as those found among Ogaden Somalis in Ethiopia. Moreover, military infiltration across the border backing such a cause can be simulated if the second term in (d) specifying military coercion is also allowed to incorporate potential derived from a fixed *Deployment Field* formed beyond the border.

(3) Complex Relationship Among Agents

In the current specification of the model, each *Ruler* is in competition with every other *Ruler*. This is often an unrealistic assumption since it is not unusual that organizations, a government as well as insurgents, become drawn into a complex web of relationships beyond mere competitions. Alliance building is one factor behind such a web. Although some form of decision-making routine like those employed in existing geopolitical simulations is required (e.g. Bremer and Mihalka 1977), if it becomes somehow possible for a *Ruler* to differentiate between an enemy and an ally, there could be many ways of relating such a distinction to state transitions of *PopCell*s. The most simple and direct way is to exclude allies of the *Ruler* that currently governs the concerned cell i from set $Q(i)$ in (d), which inhibits transitions to these allies.

(4) Toward Spatially Thick Virtual States

Lastly, the model is open to any combinations of variables and data. Focusing on spatial variables, while the shortage of substantial data is no doubt constraining, it is nevertheless possible to consider some directions in regard to enrichment of spatial settings in a virtual state. For example, by incorporating a readily accessible GIS data set such as DEM (a digital elevation model), the model can examine relevance of geographical makeup of a country to its stability in a more explicit manner than that found in the "rough terrain" debate in the civil war literature (e.g. Fearon and Laitin 2003). Likewise, with spatial data concerning distributions of natural resources (e.g. oil, diamond, etc), it is possible to conduct simulations in line with the studies relating existence of these resources to occurrence of state "failure" (Reno 1998). These data can also be consulted when assigning values to *Resources* of *PopCell*s in a virtual state.

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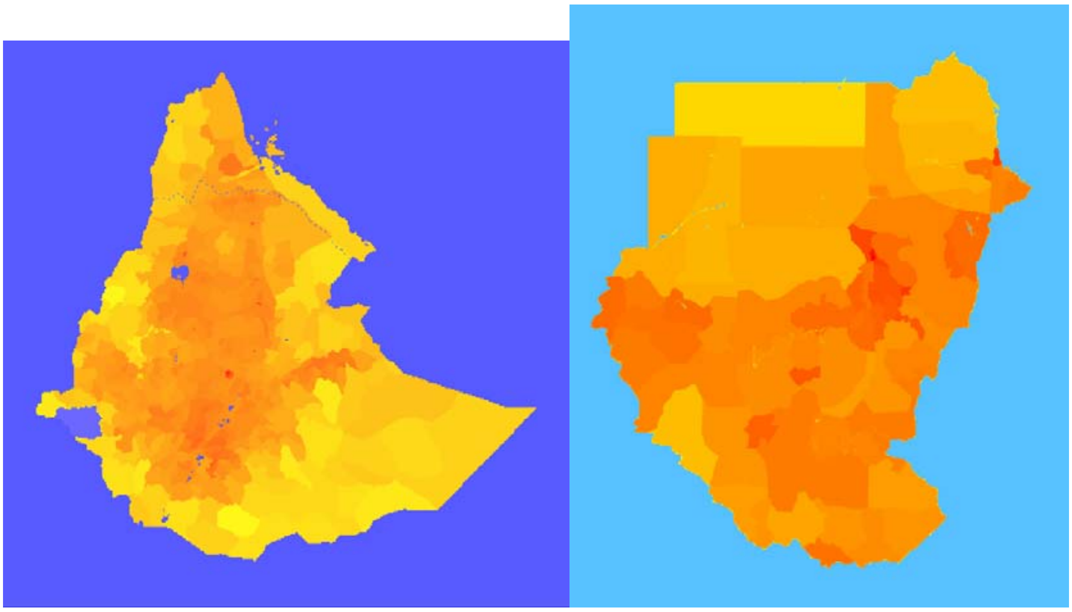

Fig.3-1 Population Distributions in Ethiopia/Eritrea and the Sudan in 1990 (from GPW)

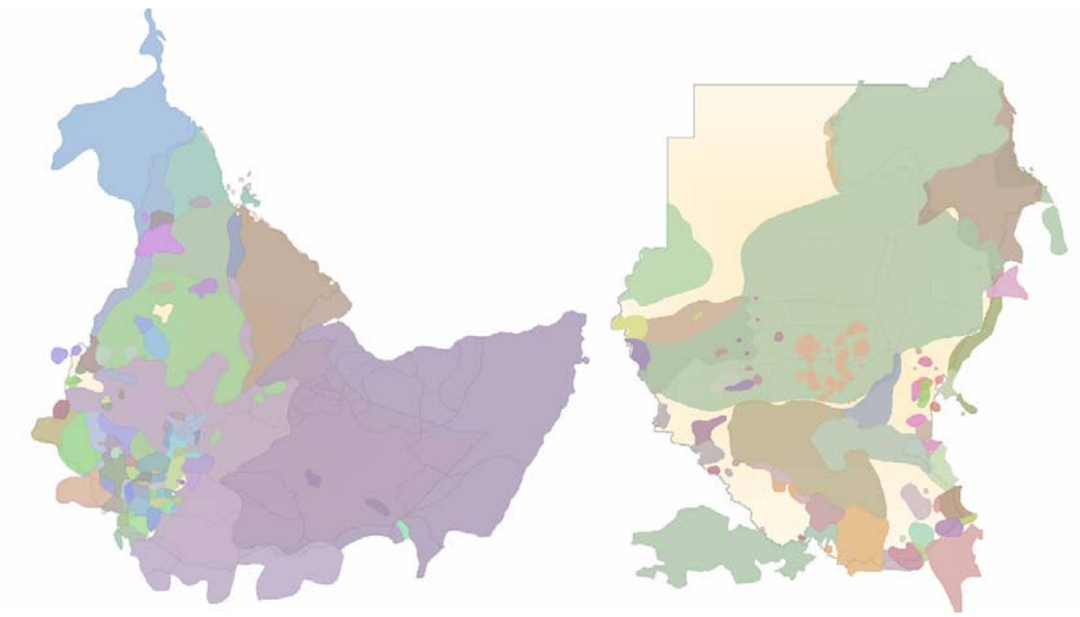

Fig.3-2 Ethno-Linguistic Distributions in Ethiopia/Eritrea and the Sudan

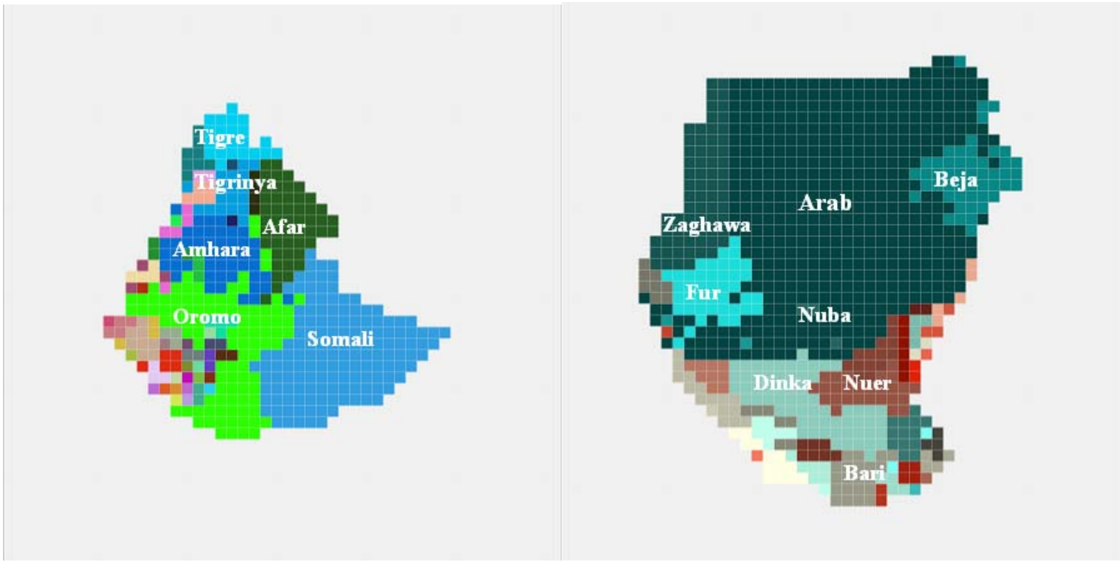

Fig.3-2 Ethno-Linguistic Distributions in Virtual Ethiopia/Eritrea and Virtual Sudan

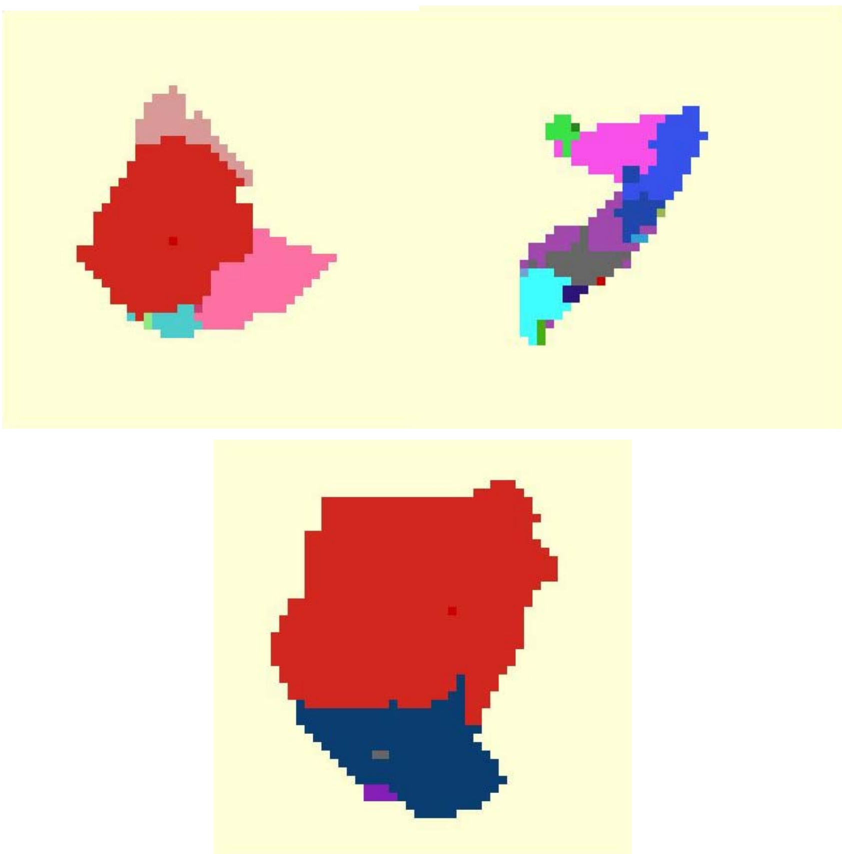

Fig.4-1 Samples of Long Term Territorial Disintegration in the Virtual Horn States

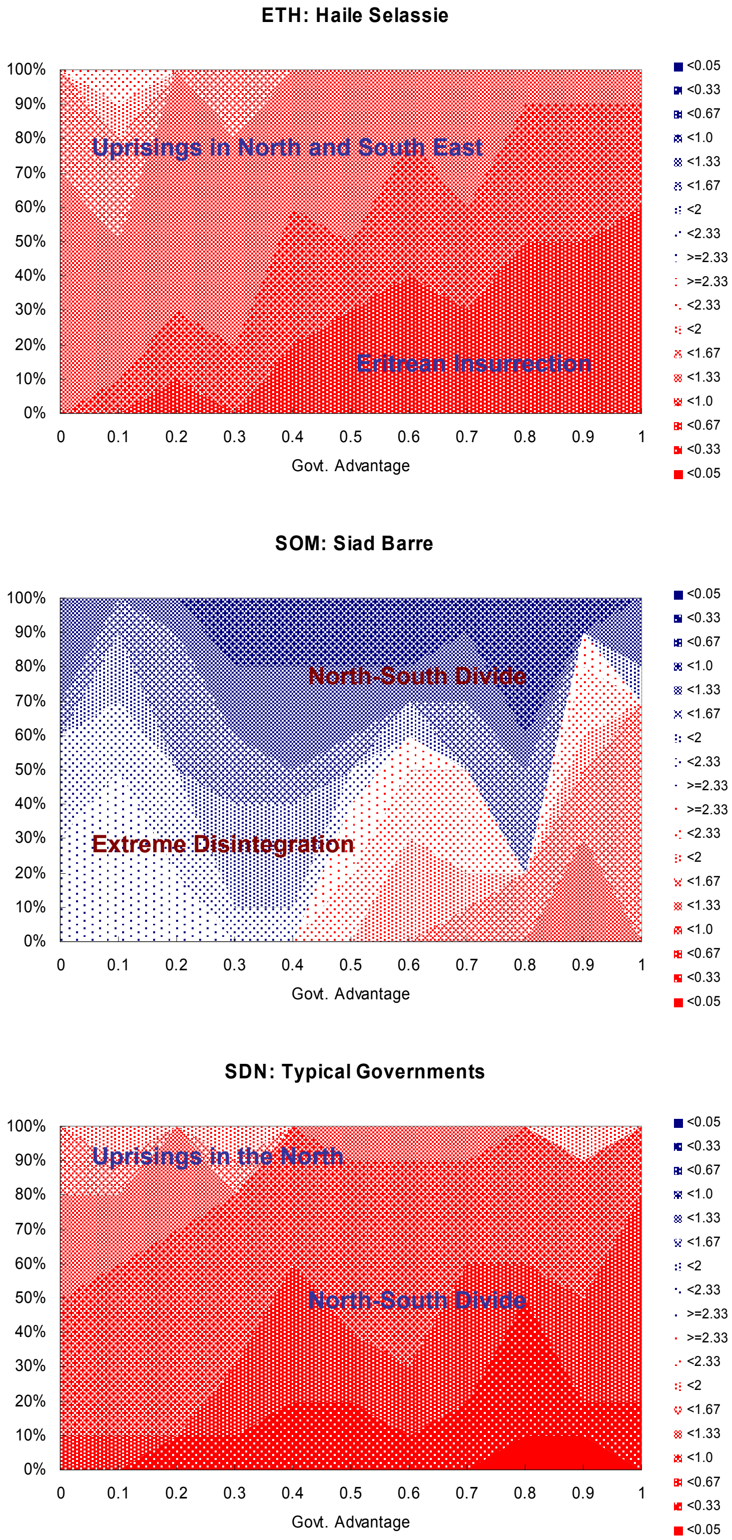

Fig.4-2 Long Term Patterns of Territorial Disintegration in the Virtual Horn States