A model for the emergence of geopolitical division

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In this work, we present a model based on a competitive dynamics that intends to imitate the processes leading to some characteristics of the geopolitical division. The model departs from very simple principles of geopolitical theory and geometrical considerations, but succeeds in explaining the general features related to the actual process. At the same time, we will propose an evolutionary explanation to the fact that most capitals (in Eurasia) are located far from the borders or coasts and, in many cases, close to the barycentre of the respective countries.

Keywords: geopolitical division; cluster growth; self-organization

1. Introduction

The combination of both a suitable theory and empirical data can render macro-historical predictions possible. This is one of the statements enounced by Collins (1995), where he accounts for a successful prediction of the break-up of the Soviet Union. The suitable theory that frames his model (Collins 1978) is a geopolitical theory for the power of the states. The history of geopolitical theory started in Germany at the beginning of the twentieth century with the work of Weber (1978) on the development of the state. But it was not until the 1970s, after many years of declining interest on the subject, that the studies on this area of knowledge flourished (Hepple 1986). Among all the processes studied by geopolitical history, the formation of the modern states system emerges as one of the most relevant, involving feedback processes between the economy, the society and the politics.

The geopolitical configuration of the continents and its evolution were a determinant factor of the economic success of several areas of the world. At the same time, it was critical in sealing the future political regimes of the nations. As complex as the spatial evolution of states might be, Collins (1978) proposed a simple theoretical model to deal with the main aspects involved in the process of expansion and contraction of the territorial power of states. The model is based on five principles that will be summarized in the following paragraph. These principles describe the factors that promote the expansion or the collapse of a nation. On one side, the expansion of states is favoured by the geographical size

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and availability of resources and by geopositional advantages, e.g. countries with fewer enemies expand at the expense of other countries with more enemies on the borders. However, on the other side, a strain of resources may arise as a result of overextension, leading to the disintegration of the state. In the same model, Collins assumes that states in the middle of a geographical region tend to fragment into smaller unities over time. Finally, the model affirms that some cumulative processes give place to long-term simplification, with massive wars between a few contenders. We can give an example of the processes foreseen by these principles. During historical periods, earlier than the technological explosion derived from the industrial revolution, the states increased their power through conquest and expansion. But this process entailed an increment in the costs of administration and military defence. Therefore, although the seek for power promoted the expansion, the increment in size and in administrative duties imposed critical constrains. At the initial stages of expansion, the increments in the wealth of a successful state exceeded the incremental costs of defending the additional new territory. However, when borders reached a critical distance from the centre of power, those costs rose faster than the benefits. As the survival of a polity depended on its military power to neutralize the constant threat posed by contiguous states, the protection of the borders was crucial (North 1981).

In the study by Jones (1981), the author analyses the interplay between the evolution of the geopolitical structure of Europe towards a system of competing states and the social development. This competing structure promoted the creation of a pluralistic environment that succeeded in constraining the power of the ruling classes, as well as the power of the states on the individuals, helping to promote institutions and legal systems that ultimately provided greater freedom than did monolithic empires. Jones affirms that the ultimate configuration of the state system in Europe cannot respond to mere geometric aspects and funds his affirmation on the analysis of a collection of complex and interconnected facts that should have influenced the whole geopolitical process. These conclusions seem to contradict the ideas of Collins, whose model is mainly based on geometrical considerations. The goal of this work is to show that although geometry cannot account for the whole geopolitical process, it does impose some constrains with important effects on the geopolitical division process. When the geometry of a given polity is closely related to other indicators, such as the military power and the availability of resources, some basic aspects of the process of political division can be derived from a model solely based on topological principles.

This task was partially accounted by Artzrouni & Komlos (1996), who analysed the spatial evolution of the European state system throughout a period extending roughly from AD 500 to AD 1800. Following this previous work, we generalize the model to include some additional aspects, such as the location of the centre of power controlling each of the states and the analysis, not only of the final configuration, but also of the temporal evolution towards the steady state.

2. The model

The model presented here is associated with a previous work by Artzrouni & Komlos (1996), where the authors introduced a spatial predatory model to trace the evolution of the political borders in Europe, from AD 500 to AD 1800.
The dynamics of the model is based on the fact that any political unit has a natural tendency to expand by conquering the neighbouring areas. A first simplistic assumption is that its perspective of success or failure in combat will depend on its military power. Following the principles stated in Collins (1978), the present model considers that the military power increases with the size of a state but decreases as a result of the over-extension of the borderline and the increment of the distance between the centre of power and the borders. Though the present model represents an oversimplification of the real historical process, it still captures the most essential features. Among the neglected features, we can mention the evolution of military technology, as well as the inhomogeneities in the distribution of the population and other economic indicators. In this version of the model, we will consider the expansion or collapse by annexation, but we will neglect the segregation of big polities into smaller units. Each country struggles for its survival by combating its neighbouring rivals. During the initial stages of the evolution, this process leads the successful countries to expand and the defeated states to shrink and disappear. The gains in wealth and power associated with the expansion exceed the incremental costs of defending the annexed territory. Some defeated countries eventually disappear, as a continuous loss of territories undermines their military power and cannot withstand further attacks from their opponents. At a later stage, the length of the expanding borders, as well as their distances to the centre, increase, making the costs to protect them go beyond the benefits of expansion. At this point, the states face the dilemma of maintaining or stopping an expansive process involving costs that become increasingly difficult to overcome.

Based on the previous considerations, Artzrouni & Komlos (1996) define the military power of a state, \( P \), as a quantity depending on the geometry of each state. It is expressed as a function of two variables: the area \( A \) and perimeter \( F \) of a country. The states are located on the top of a square lattice. The area \( A \) is simply the number of nodes of the grid occupied by the country, whereas the perimeter is the number of bordering nodes. In turn, \( P(A, M) \) is defined as

\[
P(A, M) = \frac{A}{\delta + \exp(\gamma F + \beta)}, \quad (2.1)
\]

where \( \delta, \beta \) and \( \gamma \) are positive parameters.

One of the modifications introduced in the present work is the addition of fixed centres of power or capitals with a crucial role on the dynamics of the system. The military power \( P \) will depend on the area \( A \) and on a quantity \( M \) that measures the distance between the frontier points and the centre of power. Physically, this quantity is associated with a power of the moment of inertia of the border of a country, relative to its capital,

\[
M_k = \sum_{b \in \Omega_k} [(i_b - i_{ck})^2 + (j_b - j_{ck})^2]^\alpha, \quad (2.2)
\]

where \( \Omega_k \) is the border of country \( k \), \( i_b \) and \( j_b \) are the coordinates of a border node \( b \) and \( i_{ck} \) and \( j_{ck} \) the coordinates of the capital. In the previous model, two different geomorphological aspects have been considered: the first one is the existence of natural barriers owing to topological aspects of the terrain, which inhibits only the interaction between adjacent nodes. The second one is the existence of coasts,
generally more easy to defend. We will account only for the effect of the coastal borders on $M$ through a weighting factor $\kappa < 1$. Thus, equation (2.2) results in

$$M_k = \sum_{b \in \Omega_k^1} [(i_b - i_{ck})^2 + (j_b - j_{ck})]^\alpha + \sum_{b \in \Omega_k^2} \kappa [(i_b - i_{ck})^2 + (j_b - j_{ck})]^\alpha,$$

(2.3)

where $\Omega^1$ takes into account the inland-border and $\Omega^2$ the coastal-border nodes.

$P(A, M)$ is defined as

$$P(A, M) = \frac{A}{\exp(\gamma M)}.$$

(2.4)

According to the previous discussion, we want the military power to decide the outcome of a combat, though we are interested in preserving a certain degree of stochasticity as well. Therefore, we follow the prescription proposed by Artzrouni & Komlos (1996). After measuring the $P$-values of the two confronting countries, we call $P_h$ and $P_l$ the higher and lower $P$-values, respectively. This identification is irrelevant in the case of equality and can be randomly done as shown later. Next, we assign the victory to the country with the higher military power with a probability

$$\phi_h = 1 - 0.5 \exp \left( -k \left( \frac{P_h}{P_l} - 1 \right) \right),$$

where $k$ is the parameter that tunes the deterministic character of the dynamics. The higher $k$-value denotes the higher possibility of the strongest country to win. The weakest country wins with a probability $\phi_l = 1 - \phi_h$. In case of equality, the probabilities are $\phi_l = \phi_h = 0.5$. The same is true when $k = 0$, and the systems evolve in a random way.

The analysis of equations (2.1) and (2.4) clarifies the idea that $P$ is a quantity that contains information about the military power of a state and about how efficiently this power can be used. The area $A$ favours the economic power and population size. But beyond a certain threshold level of spatial expansion, the military power becomes less effective since more resources are needed for the defence of the enlarged frontier. On the one hand, $P$ is a monotonic increasing function of $A$, indicating that a greater area represents a potentially higher power. On the other hand, a bigger area can inhibit the efficient exertion of that power by effects of the state’s geometry. This fact is taken into account in the dependence of $P$ on $F$ or $M$. As an example, we will consider a state represented by $n^2$ territorial unities. In two extreme situations, the state can be an $n \times n$ square or an $n^2 \times 1$ rectangle. Though both states have the same area, the rate perimeter surface is lower for the square state; consequently, according to equation (2.1), its military power is higher. A similar conclusion can be derived when considering equation (2.4). According to Steiner theorem, the moment of inertia of a plane figure is minimum when it is calculated about an axis located at the centre of mass. Therefore, among all the states with identical shape, the one with its capital being the closest to the centre of mass will present the lowest value of $M$. A possible observation to the situation described above is the fact that borders closer to the centre of power should be easier to protect than those far away.
At the same time, a wiser military strategy will tend to focus the defence of the country on the borders but without neglecting the capital. To consider these facts, we introduce a further modification of equation (2.4) by including a local term that accounts for the relative distance between the capital and the border points involved in a specific conflict, i.e. the points at the border with the eventual opponent country. The military power then presents a global term plus a local factor associated with the conflictive border. We redefine $P$ as

$$P(A, M) = \frac{A}{\exp(\gamma MM_l)}. \quad (2.5)$$

The calculation of $M_l$ is analogous to that of $M$ but restricted to the border under conflict, i.e. $\Omega^1$ and $\Omega^2$ in equation (2.3) refer only to the partial border.

As we will show later, the dynamics of this system can be associated with a cluster-growth process. Although there is a vast literature on this area (Langer 1980; Heermann & Klein 1983; Vicsek & Family 1984; Stanley et al. 1985; Herrmann 1986; Vandewalle & Ausloos 1996) and some of these works might show some common features with the one described in this work, the present model includes some unique features closely related to the particular problem analysed here. In §3, we discuss the results obtained in each case.

### 3. Results

Throughout all the simulations, we have maintained the same initial condition. At the beginning, the system is composed of 400 states, each one being a square comprising $3 \times 3$ surface unities with the capital located at the barycentre. The whole system is a square lattice of $60 \times 60$ surface unities. During the first stages of the simulation, the dynamics of the system is almost random. Later, some differences among the shapes of the states arise and play a defining role in the further evolution of the system. In order to obtain a correct interpretation of our results, we first analyse the behaviour of a system driven by a random dynamics throughout the whole simulation, neglecting the dynamics proposed in this work. This can be very easily achieved by considering that the outcome of a fight is uncorrelated to the military power of the confronting countries. In this case, the winner is randomly chosen. Figure 1 summarizes the main findings: the dynamics of the model drives the system to the conformation of a unique big country having conquered all the available territory. The plot shows how the collapse of the smallest countries produces an exponential time decay in the number of survival states, $N_s$, with a slowing down when the number of remaining countries is around 10. At this point, the disappearance of a state takes much longer. Finally, the system converges to its only steady state: a unique state.

This trivial stochastic evolution turns much more interesting when we introduced the dynamics proposed in our model. In this case, it is the value $P$ that defines the victorious country. During the first stages of the evolution, we expect the states having values of $P$ proportional to their sizes, as was discussed above. This tendency changes after a transient letting to the disappearance of the majority of the countries. Once the surviving countries have reached their critical sizes, their military power decreases due to overextension. At this point, the increasing value of $F$ or $M$ dominates the evolution of the dynamics.

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This critical size can be analytically estimated. We assume that we are analysing the evolution of the military power of a state that expands in the optimal way. Considering equations (2.1) and (2.4), we can state that the optimal shape adopted by an expanding state is the circular one. In our analysis, and only for simplicity, we will consider the octagonal shape. Furthermore, if the location of the capital is taken into account, $P$ is maximized when the former is located on the centre of mass of the corresponding state.

We define $r$ as the radius of the circle circumscribing the octagon. As discussed previously, an expanding state will increase its military power until a critical value of $r$ is attained. At this point, the effects of the overextension will start to become noticeable. We want to estimate the maximum attainable value of $P$ at this critical radius $r_c$. If we analyse equation (2.1), considering that a state expands preserving an octogonal shape, we can find an approximate value of $r_c$, the point when the maximum military power is achieved. We note that the quantities $A$, $F$ and $P$ can be written in terms of $r$,

$$
\begin{align*}
A(r) &= 2 \left( 2 \sin \left( \frac{\pi}{8} \right) r \right)^2 \left( 1 + \sqrt{2} \right), \\
F(r) &= 16 \sin \left( \frac{\pi}{8} \right) r \\
\text{and} \\
P(r) &= \frac{A(r)}{(\alpha + \exp(\gamma P(r) + \beta))}.
\end{align*}
$$

Figure 2 shows the value of $P$ according to the expression in equation (3.1) in the $(r, \gamma)$ plane. The existence of critical radius $r_c$ is evident. Deriving the last expression of equation (3.1) with respect to $r$, let us find $r_c$, which gives the following expression:

$$
e^{\beta + 16 r_c \gamma \sin(\pi/8)} \left( 8 r_c \gamma \sin \left( \frac{\pi}{8} \right) - 1 \right) - \alpha = 0,$$

Figure 1. Time evolution of $N_s$, the number of surviving states, for a random dynamics.
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Figure 2. The value of $P$ given by equation (2.1) is plotted in the $(r, \gamma)$ plane. We observe a non-monotonic behaviour and the existence of a critical radius determined by the maximum value of $P$. $\alpha = \beta = 1$.

Figure 3. The plot shows $N_s$ versus $\gamma$ for the case associated with equation (2.1), $\alpha = \beta = 1$. The dashed line corresponds to fitting the data with a parabola.

with a solution for $r_c$ in terms of Lambert’s $W$ function,

$$r_c = \frac{2 + W[2\alpha \exp(-2 - \beta)]}{16 \sin(\pi/8) \gamma}.$$ (3.3)

The former expression shows us that the critical radius is inversely proportional to $\gamma$. Considering a fixed size for the total territory, the mean size of the countries is inversely proportional to the square of their mean radius. In this case, we get the following relation: $N_s \propto \gamma^2$. This is precisely what we get when plotting the numerical data on the $(N_s, \gamma)$ plane and we fit them with a parabola. Figure 3 shows the mean value of $N_s$, the number of surviving states at the end of the evolution, as a function of $\gamma$. The resulting points were fitted with a parabola, also displayed in the plot.
Figure 4. $N_s$ versus $\gamma$ for the case associated with equation (2.4), $\alpha = 1$. The scales are logarithmic. The dotted line has a slope equal to $2/3$.

When we take the location of the capital into account, we get the following expressions:

\[
\begin{align*}
A(r) &= 2 \left( 2 \sin \left( \frac{\pi}{8} r \right) \right)^2 (1 + \sqrt{2}), \\
M(r) &= 2(2 + \sqrt{2}) \sin \left( \frac{\pi}{8} r \right) r^{2\alpha + 1}, \\
B(r) &= \frac{A(r)}{\exp(\gamma M(r))}.
\end{align*}
\] (3.4)

In this case, the critical radius is inversely proportional to $\gamma^{1/(2\alpha+1)}$, therefore $N_s \propto \gamma^{(2/3)}$. Figure 4 shows an example of the fitting of numerical data when $\alpha = 1$. The fitting shows us that $N_s \propto \gamma^{(2/3)}$.

This analysis is not applicable to equation (2.5) because it involves not only the geometry of the analysed state, but also that of its neighbours as well as local considerations.

All the data on figures 3 and 4 correspond to averages over 1000 realizations for each point. The number of surviving states $N_s$ reaches a stationary value, maintained over at least 50,000 time steps, 10 times longer than the time it takes for the system to reach the steady value. Although the number of surviving states remains constant, the system is not frozen. We can observe changes in the shapes and sizes of these surviving countries because of persisting combats. Nevertheless, these fights do not change the conformed map significantly. The results let us confirm that the system evolves showing some countries expanding at the cost of the collapse of others, until a metastable situation is achieved.

At this point, the analysis of the model described by equation (2.1) is almost finished, except for the study of the shape and size distribution of the surviving countries.
To statistically analyse the geometry of the surviving countries, we measure how far from a circle or octagon their shapes are. We consider a quantity $\rho$ herewith defined. First, we measure the distance $d_{i,0}$ between each point $i$ on the borderline of the country and its centre of mass. Then, we calculate $\rho$ as the ratio between the variance of this distance and the area of the country, $A$. If a country is circular, this quantity is equal to zero, while it is approximately 0.00112 for an octagon. The expression for $\rho$ is then

$$\rho = \frac{1}{A} \left( \frac{1}{N_\Omega} \sum_{i \in \Omega} (d_{i,0})^2 - \left( \frac{1}{N_\Omega} \sum_{i \in \Omega} d_{i,0} \right)^2 \right). \quad (3.5)$$

In figure 5, we plot $\rho$ versus the number of surviving states, $N_s$. The filled dots correspond to the present case. We observe a sharp transition as the number of surviving countries grows from 1 to 3. The lower value, $\rho \approx 4 \times 10^3$ corresponds to a unique squared country limited by the shape and size of the lattice. The value of $\rho$ then stabilizes around $5 \times 10^2$. As a reference, we mention that the extreme case of a rectangular, almost one-dimensional country will give us $\rho \approx 10$, when $\gamma = 0.1$. The results show us that the surviving states avoid oblong shapes, but still we need to compare these results with those obtained when the capital of the state is taken into account. The variation in size, whose mean value is associated with the mean number of surviving states depicted in figure 3, is around 50 per cent when the number of surviving countries is over 5, then it decreases abruptly to 0.

The introduction of capitals allowed us to add to the previous analysis the study of their locations and the centrality of the respective countries. One of the aspects we want to analyse by means of the modification introduced to the original model is precisely where the capitals of the surviving countries are located. Figure 5 also shows the behaviour of $\rho$ in this case, plotted with empty
circles. The most evident fact is that the values are lower than in the previous case, indicating that the countries adopt a more symmetric and circular shape. The results do not differ too much if we consider either equation (2.4) or equation (2.5).

When considering the location of the capital, not only can we measure $\rho$ but we can also calculate the distance between the centre of mass and the capital. To compare the previous distance with a characteristic length, we choose the mean radius of the country. We define $\delta_{c0} = d_{c,0}/r_m$, where $d_{c,0}$ is the distance between the capital and the centre of mass and $r_m$ is the mean radius.

Figures 6 and 7 show the distribution of $\delta_{c0}$ for different values of $\alpha$ and $\gamma$ for the cases described by equations (2.4) and (2.5), respectively. In this case, there is an evident difference in the behaviour of the system. The values of $\alpha$ and $\gamma$ were adjusted to get a final configuration with the same number of surviving countries in each case. We can observe that if we consider local aspect related to the military power and the cost of defending the borders, we get capitals located closer to the centre of mass of the states.

To provide a more graphical example of the results, we present the outcome of three single realizations in figure 8, together with a representation of the time evolution of the sizes of the surviving countries.

Each realization corresponds to a different choice for $P$. Group (a) corresponds to the model that does not take into account the location of capitals (equation (2.1)), while (b) and (c) differ in which the last one reflects the state of a system, where $P$ is affected by local contributions (equation (2.5)), and (b) corresponds to equation (2.4). When we observe the temporal evolution of the size of the surviving countries, the differences are rather evident. The curves related to the model associated with equation (2.1) present fluctuations of great amplitude. This behaviour reflects in the distribution of sizes of the states than can be observed in the map showing an instantaneous picture of the system. At a given moment, some countries can be six times bigger than others. If fluctuations are strong enough, they can lead the system to a trivial state. On the other hand,
Figure 7. Distribution of $\delta_{c0}$ for different pairs of values of $\alpha$ and $\gamma$ with $\langle N_s \rangle = 10$. The plot corresponds to the case associated with equation (2.5).

Figure 8. (a–c) Maps and size evolution of the surviving countries for three different cases.

Groups (b) and (c) show a more steady behaviour. After a transient, the size of the countries stabilizes, suffering only very small fluctuations. At the same time, the distribution of sizes is more even. Groups (b) and (c) differ in that the effect of local considerations is the centralization of the capitals, shown by stars on the map. This effect was already discussed in figure 7.
4. Conclusions

Supported by the fact that the historical evolution of geopolitics is a complex process involving a huge variety of causes and effect, the conception of simple models explaining general aspects has been neglected. This fact is the main motivation behind the present work. It is not the intention of this model to provide an accurate and complete description of the process that shaped the present political division of the world. On the contrary, its more modest goal is to show that some general features can be explained departing from very simple assumptions. Based on the ideas sketched by Collins (1995, 1978), we have developed a model that has succeeded in reproducing a series of geopolitical phenomena. Among them, we were able to reproduce the fact that most of the capitals are located in a central position and the fact that most of the surviving countries have costs, with only a few being inland. At the same time, we have found that it was possible to find a stable political division with many countries of similar size and overall shape, but also reproduce a situation when a huge conquering Empire rises. Still the model needs some adaptation to be able to describe the sort of processes that have occurred in the United States and Africa, and include the possibility of state segregation. These aspects will be taken into account in future work.

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