The Formation of the European State System

A Spatial "Predatory" Model

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The formation of the European state system was an important determinant of the economic success of that continent insofar as the articulated system of competing states created a pluralistic environment that set constraints on lords and monarchs, as well as states, to extract rents from their subjects. The competition among political jurisdictions also provided incentives to create institutions and legal systems conducive to the respect of private property that ultimately provided greater freedom than did monolithic empires (Jones 1981, 104). This freedom enabled individual entrepreneurs to pursue their self-interest, to exchange goods and information, and thereby to increase their own wealth as well as that of their nations. The absence of universal empires in Europe also meant that minorities could not be prosecuted without cost; they could migrate and thereby enrich competing political units. As a consequence, the way in which this political structure came into being is certainly worth exploring.

In this article we conceptualize the spatial evolution of the European state system through a simulation model that covers the period extending roughly from A.D. 500–1800. Our goal is to investigate whether such a model can help us to better understand how the state system could have come into being.

We assume that in the preindustrial world, power increased with the size of a polity, but in the process of expansion the costs of administration (including tax collection) and of military defense also rose as a result of overextension. Whereas the first principle induced states to expand, the latter tended to restrain them. In the immediate vicinity of centers of power, the increments to wealth associated with conquest were generally greater than the incremental costs of defending the additional territory. However, as distances from the center increased, the costs increased faster than the benefits and must have eventually exceeded them. Therefore, with a given level of military and communication technology and administrative efficiency, the sovereigns came up against countervailing forces to further expansion that became increasingly difficult to surmount as distance from their center of power rose. Thus, while the concomitant benefits induced states to attempt to expand their boundaries, the costs associated with conquest posed an effective limit beyond some optimal size after which the marginal revenues provided by additional subjects were less than the marginal cost of defending them from envious and predatory neighbors.

Needless to say, the very existence of a polity depended on military power, which was an important factor given the constant threat posed by contiguous states (North 1981, 205–6). The Middle Ages witnessed innumerable wars and skirmishes, as a consequence of which territories changed hands incessantly. In fact, the borders of European states remained fluid well into the nineteenth century, as the numerous wars of even this relatively "peaceful" epoch testify. The provinces of Alsace-Lorraine, Schleswig-Holstein, Lombardy, Venice, and Bosnia-Herzegovina were just some of the objects of repeated strife during the latter half of that
century. In the Balkans and to a certain extent even in Eastern Europe, the borders remain contested into our own day.

Financial and cost factors determined, in the main, the size of the military at a state’s disposal that could be effectively commanded from the center of power. To be sure, an increase in size generally brought with it an increase in the number of subjects and hence of the tax base, as well as additional recruits for the army. However, given the rudimentary communication and transport technology of the preindustrial world, the transaction costs associated with governing (and defending) distant parts were high. As a consequence, spatial expansion also meant that governing distant lands became more formidable because the costs of maintaining communication, as well as commanding and resupplying armies on the borders, became not only more difficult but also more uncertain and therefore prohibitively costly. In short, no state could expand indefinitely.

We assume that these offsetting forces (one favorable to expansion and the other opposed to it) gave rise to an optimum size and shape of a state. An equilibrium was reached in the long run: if it became either smaller or bigger, the state became less powerful and thus more vulnerable. To be sure, that optimum depended on geographic considerations and increased as the technology of warfare, administration, transportation, and communication improved over time. Shifts in the aggregate production function, which increased or decreased taxable income, would have had analogous effects (Bean 1973; Blum and Dudley 1991).

The Model

1. Spatial assumptions. The conceptualization of our model will be analogous to the formation of boundaries between competing market areas, with the difference that in our case instead of a commodity it is military power, a public good, that is being supplied within a particular region (Lösch [1940] 1954). The model does not incorporate the effects of changes in military technology, such as the introduction of artillery, that brought about economies of scale in government size (North 1981, 66; Latzko 1993). Such extensions are left to future versions of the model.

In addition, we assume that population is evenly distributed throughout the spatial extension of Europe, that labor is equally productive everywhere, and that the tax rate and structure as well as military technology are also identical throughout. In other words, we do not allow relative levels of economic development to influence military power and subsequently to determine the extent of the polity. Moreover, we do not model strategic behavior in forming alliances or intertemporal effects, such as increases in the savings rate, that would enable a monarch to forego current conquests for possible larger military gains in the future.

For the purpose of computer implementation, Europe is conceptualized as a grid of small squares of side 1, where this unit corresponds to approximately 40 km. The two variables of the model are the area $A$ of a country and its perimeter $C$. The area $A$ is measured as the number of unit squares that make up the country, and $C$ is the number of unit squares that have a foreign neighbor. This measure of the perimeter is convenient when shapes are irregular (which is always the case during the simulations).

Natural barriers are not counted into the perimeter to the full extent. Because coasts are generally more easily defended than inland plains, each unit of “coastal border” is counted as a fraction $f$ of a unit of “land border.” In addition, the Pyrenees and the Alps are assumed to be impregnable natural barriers even though this exaggerates their true strategic importance. However, the Pyrenees do not extend completely between the Atlantic and the Mediterranean, thus reflecting the geographic reality of coastal corridors that were used to move armies between Spain and France. In addition, the Alps do not extend all the way to the Mediterranean, which leaves the possibility of expansion through the corridor between the southern Alps and the sea.

2. State building: Military power and spatial extension. The outcome of wars in our model depends essentially on military power, on the desire for conquest, on chance, as well as on geographical considerations. We thus define a function $P(A, C)$ of the area $A$ and the perimeter $C$ that is analogous to a production function but is more than that: $P(A, C)$ is a composite of military power and “demand” for military power, that is, the extent to which military power can be used effectively. The assumption is that the area is a proxy for both economic power and population, the two main ingredients of military might during the period under consideration. The functional dependence on $C$ will be used to express in a simplified manner how power depends on the shape of a country.

In accordance with the previously outlined principles, we postulate that the power function $P(A, C)$ has the following characteristics: when a country is small, $P(A, C)$ increases with the area $A$, but once the perimeter $C$ reaches a certain length, overextension begins, and $P(A, C)$ then decreases. Thus, military power becomes less effective beyond a threshold level of spatial expansion, inasmuch as defense must be provided on a larger frontier against a number of rivals.

The function we have chosen is of the form:

$$P(A, C) = \frac{A}{\alpha + e^{\gamma C^{\beta}}}$$

where $\alpha, \beta, \gamma$ are positive parameters.

Let us first look at this function when one variable at a time is held constant. If $C$ is constant, then $P(A, C)$ is a linear function of $A$. Think of a string (representing a fixed perimeter $C$) tied together at both ends that can be formed into any shape. Because one can make a long, thin band of area $A$ close to zero (in which case $P(A, C)$ is also nearly 0), the area and therefore economic power and population are then close to 0. The maximum area enclosed with that string of length $C$ is that of a circle with circumference $C$. The
power \( P(A, C) \) is then maximum because the area and population are maximum for the same border length \( C \).

On the other hand, if \( A \) is constant, \( P(A, C) \) is a decreasing function of \( C \), thus reflecting the inverse relationship between a country’s ability to defend itself and the length of its border. The area \( A \) has a minimum perimeter \( C \) when the country is shaped as a circle (it can then best defend itself). If \( C \) increases while \( A \) remains constant, the same population must defend longer borders, and the country’s effective military power decreases. This justifies \( P(A, C) \)’s being a decreasing function of \( C \) for fixed \( A \).

Now let us look at the more realistic example when \( A \) and \( C \) increase simultaneously. For a sufficiently small \( \gamma \), the denominator in equation (1) remains close to \( \alpha \) as long as \( C \) is small, and \( P(A, C) \) thus grows linearly as \( A/\alpha \). As a country expands, both \( A \) and \( C \) increase. When \( C \) grows significantly, the exponential term eventually overwhelms the linear growth of \( A/\alpha \), and the function goes to 0.9

For a better understanding of the function \( P(A, C) \), we assume for the moment that a country remains square while it expands. If \( x \) is the side of a square country, then \( A = x^2 \).

With our definition of the perimeter, \( C \) is \( 4(x - 1) \) for \( x > 1 \). The function \( P(A, C) \) thus becomes a function \( P^*(x) = P(x^2, 4(x - 1)) \) of the side \( x \):

\[
P^*(x) = P(x^2, 4(x - 1)) = \frac{x^2}{\alpha + e^{\gamma(x - 1)} + \beta}.
\]

We found it convenient to reparameterize the function \( P^*(x) \)—and therefore \( P(A, C) \)—by defining the parameter \( s^* \) as the side of the square for which the function \( P^*(x) \) reaches its maximum. For fixed \( \alpha \) and \( \gamma \) (which are shape parameters) and a given \( s^* \), it can be shown that the corresponding function \( P^*(x) \) is obtained by choosing \( \beta \) as

\[
\beta = \ln \left( \frac{\alpha}{2s^* - 1} \right) - 4\gamma s^* + 4\gamma.
\]

An example of the function \( P^*(x) \) for the power of a hypothetical square country of side \( x \) is given in figure 1. The parameter values are those used in the simulation \( (s^* = 15, \alpha = 1.00, \gamma = 0.035 \), and therefore \( P^*(x) \) reaches its maximum when the country’s side is 15 units long, i.e., 15 x 40 km = 600 km).  

3. The simulation. Given that during the Middle Ages state boundaries were not yet fully formed, we assume as a simplification that in A.D. 500 the continent consisted of a mosaic of small square political units of side 5. Therefore all units initially have the same area of \( (5 \times 40) (5 \times 40) \) 40,000 sq. km and are equally powerful.10 These political units, or countries, all have the same power \( P(25, 16) = P^*(5) \), except for those that have a maritime border—the fraction \( f \), discussed previously, decreases their calculated perimeter and makes them slightly easier to defend.

The model runs as follows: A country \( X_n \) (with area \( A_n \) and perimeter \( C_n \)) is chosen at random with a probability proportional to its size.11 Its power \( P(A_n, C_n) \) is then compared with the powers \( P(A_i, C_i) \) of all its neighbors \( X_i \) \((i = 1, 2, \ldots, n, \) where \( n \) is the number of neighbors). Given that states are assumed predatory, we postulate that the greater the difference in power between bordering states, the higher the likelihood of conflict.12 We therefore choose the neighbor \( X_i \) that has the greatest power differential with \( X_n \), that is, \( I_n^* \) is the index of the country for which the absolute value \( |P(A_n, C_n) - P(A_i, C_i)| \) is maximum. Therefore \( X_n \) is a country that is either much more powerful or much weaker than \( X_n \), and these two countries then go to war. We next describe the mechanism that determines the winner and what it means to win a war.

Let \( P_i \) be the (low) power of the weaker country and \( P_H \) be the (high) power of the stronger of the two countries (i.e., \( P_i = \min(P(A_n, C_n), P(A_i, C_i)) \), and therefore \( P_i \) is always less than or equal to \( P_H \)). The stronger country wins with a probability \( \pi(P_H/P_L) \) (also known as the Contest Success Function—CSF) that depends on the ratio \( P_H/P_L \). We chose for \( \pi(P_H/P_L) \) the functional form

\[
\pi(P_H/P_L) = 1 - 0.5 \exp \left( -K \left( \frac{P_H}{P_L} - 1 \right) \right)
\]

where \( K \) is a positive constant.13 Hence the weaker country wins the conflict with probability \( 1 - \pi(P_H/P_L) \). This rule is implemented by drawing a random number \( N \) uniformly distributed between 0 and 1 and letting the stronger country win if \( N \leq \pi (P_H/P_L) \), and the weaker one win if \( N > \pi (P_H/P_L) \). To win means to annex the border region of the loser; that is, all the loser’s unit squares of territory contiguous to the winner are absorbed by the winner.

Equation (4) shows that the stronger country wins with a probability that is always larger than .5 and becomes closer to 1 as the ratio \( (P_H/P_L) \) increases. Indeed, if \( P_H \) is just slightly larger than \( P_L \), then \( P_H/P_L = 1 \) is close to 0, and \( \pi(P_H/P_L) \) is close to .5 because the argument of the expo-
ential term is close to 0; both countries have approximately the same probability of winning.\textsuperscript{14} If, however, $P_H$ is significantly larger than $P_L$, then the exponential term is small and $\pi(P_H/P_L)$ is close to 1. In other words, the probability that a significantly more powerful country will win approaches 1 as the difference in power increases.

The parameter $K$ in equation (4) is a "measure of randomness." Indeed, if $K$ is very small, then $\pi(P_H/P_L)$ tends to be close to .5, regardless of the values of $P_1$ and $P_H$. (The system is "very random.") In contrast, if $K$ is large, then as soon as $P_H$ is just slightly larger than $P_L$, $\pi(P_H/P_L)$ tends to be close to 1\textsuperscript{15} (The system then is "nearly deterministic" because the more powerful country will almost always win.)

We chose $K$ by deciding for what value $r^*$ of the ratio $P_H/P_L$ we wanted $\pi(P_H/P_L)$ to be equal to .9. This relation implies that

$$ K = \frac{\ln(5)}{r^*-1} $$

and we can therefore rewrite equation (4) as

$$ \pi(P_H/P_L) = 1 - 0.5 \exp\left(\frac{\ln(5)}{r^*-1} \left(\frac{P_H}{P_L} - 1\right)\right) $$

(6)

The function $\pi(P_H/P_L)$ is known when $r^*$ is known and is depicted in figure 2 for $r^* = 1.5$. (This value is later used for the actual simulations.)

In short, each iteration of the model is made of one bilateral war: A country chosen at random goes to war with a neighbor either much more or much less powerful (relative to other neighbors), and the winner annexes the border region of the loser. At the end of each such war, the iteration is repeated; a new country is chosen at random, and another war breaks out. We thus expect a slow evolution of the borders of Europe to occur uniformly across the continent.

Figure 3 displays the algorithm in flowchart form. Each iteration (and each war) corresponds to four months. The period a.d. 500–1800, therefore, takes $3 \times 1,300$ or 3,900 iterations.

4. **Calibration of the model.** The parameters of the model are the fraction $f$, the constants $\alpha$, $\beta$ (or $s^*$), and $\gamma$ of the production functions $P(A, C)$, and the value $r^*$ that determines the degree of randomness of the model. These parameters were chosen by trial and error to find values for which the model would produce a dynamic map of Europe that would replicate the general thrust of history as accurately as possible. We found $f = 0.95$ and $\alpha = 1.00$, $\gamma = 0.035$, and $s^* = 15$: these last three parameters define the function $P(A, C)$ and the related function $P^*(x)$ giving the power of a hypothetical square country of side $x$ (figure 1). We chose $r^* = 1.5$, which means that the probability of the more powerful country's winning is .9 when the more powerful country is 50 percent more powerful than the weaker one. The corresponding function $\pi(P_H/P_L)$ is given in figure 2.

**Results and Discussion**

The result is a striking color mosaic of initially small, square countries with slowly shifting borders that evolve over time as some countries expand while others disappear. The unfolding map of Europe thus reflects the historical record of small political units slowly giving way to large, stable nations.\textsuperscript{16} The maps were printed at three points in time: At the onset of the simulation, circa a.d. 500; at the midpoint in a.d. 1150 after 1,950 iterations; and at the end of the simulation, in a.d. 1800, after 3,900 iterations (figures 4a–c).

Figures 4a–c show that, despite its simplicity, the model replicates quite well the general dynamic evolution of the borders of Europe through time since the early Middle Ages. Indeed, starting in a.d. 500 with a fragmented Europe consisting of 234 small, square political units, the model generates 1,950 conflicts during the next six hundred fifty years. These wars resulted in the disappearance of many countries, with only 40 left by 1150. The map (see figure 4b) shows that in 1150 a number of nations were beginning to take shape, which is in good agreement with the historical record. Indeed, the similarity with historical maps for that period is noteworthy [see, for example, the map of Europe circa 1190 in The New Encyclopaedia Britannica (1988, vol. 18, p. 702) taken from Shepherd (1964); see also the maps in McEvedy (1992)]. During the next six hundred fifty years, there are another 1,950 conflicts, with the number of countries decreasing slowly to 25 by 1800 (figure 4c).

The model's output (see figure 4c) is a stylized representation of the borders of Europe in 1800. Although one could not expect the model to replicate the details of all the borders of the European continent at that time, the outlines of
France, Spain, Germany, and Italy are clear, with several smaller nations to the east. At that time, the model appears to have reached a rough equilibrium, with the number of countries decreasing only very slowly.

Through repeated runs of the model, it becomes clear that Western Europe usually acquires its stylized outline early in the exercise (around the 16th to 17th century, with only minor fluctuations thereafter). The emergence of Central Europe, in contrast, generally takes longer, and the outcome is more uncertain than in the West. This can be interpreted as corresponding to the late and tenuous formation of the states in that region. Furthermore, the model suggests that in Eastern Europe the simulation provides a picture that is even more fluid, coagulation taking longer, with the outcome considerably more uncertain; but it is arguable that this state of affairs does conform to that region's history.

The model demonstrates that spatial and geographic factors help explain the faster organization of the borders in the western part of the continent. Because of the presence of maritime borders, some countries in the West have fewer neighbors, which may bring about a more rapid absorption by others if these countries are weak, or a more rapid expansion if they are strong. In contrast, the large open spaces in the eastern parts of the continent increase the
FIGURE 4a
Initial Map of Europe (A.D. 500; $x^* = 15$)

FIGURE 4b
Model Output after 1,950 Iterations (A.D. 1150; $x^* = 15$)
chances of survival of small countries, as each country has, a priori, more neighbors (this may decrease the chances of complete annexation).

The parameter $s^*$ was set equal to 15 because a square country that reaches its maximum power for a side of 15 is made of nine original $5 \times 5$ states put together. Such a country has an area of $9 \times 25 \times 1,600$, or 360,000 sq. km that can be inscribed in modern-day France (see figure 4a). The idea was to ascertain whether the model could eventually produce countries that at an equilibrium would be at their maximum power and have realistic areas in the range between 300,000 and 600,000 sq. km. Although not directly relevant (inasmuch as countries do not remain square, and the maximum of the function $P(A, C)$ is then not easily defined), this simple specification was useful in finding the parameter values for which the large nations of Western Europe would eventually reach an equilibrium with realistic sizes and borders.\textsuperscript{17}

A sensitivity analysis shows that relatively small changes in the parameter values can bring about quite different outcomes that do not conform well with the historical record. For example, when $s^*$ is set equal to 20 instead of 15 (with the same values for $\alpha$ and $\gamma$), a typical endpoint of the model in A.D. 1800 is given in figure 5. Not surprisingly, there are fewer countries than in figure 4c, and they are larger, as one might expect, because at least in the idealized case of a square country a nation can become larger than in the previous scenario before it overextends itself. The phenomenon was even more pronounced for $s^* = 25$: countries became huge, and by the year 1800 there were fewer than 10 countries left.

Finally, the results are quite sensitive to the parameter $f$. For values of $f$ around 0.7, the simulations usually yielded one or two countries with maritime borders to the west of Europe that swept eastward across the continent; their small calculated perimeters kept their power high, and they annexed all their neighbors.

**Conclusion**

We have described a simple spatial predatory model that simulates the dynamics of state boundaries on the European subcontinent. However, it should be obvious that the model's frugal specifications cannot be expected to duplicate precisely the borders of all states in Europe at any given time. That was not our goal. Although France, Spain, Germany, and Italy emerged from the simulations partly as a result of geographic constraints, the sensitivity analysis shows that the model needs to be finely tuned by finding parameter values for which the dynamic map of Europe reaches the desired...
equilibrium. The model has enabled us to explore the determinants of this equilibrium as well as the more fluid spatial dynamics in Central and Eastern Europe.

Many details have been overlooked in a model that uses two simple spatial variables to capture the vagaries of history over the centuries. However, the realistic results produced by the model demonstrate that with frequent wars, even without considering the role of military leadership, ideology (such as religion or nationalism), or economic strength, forces inherent in the location of states suffice to determine the salient features of the modern European state system. Our conceptualization thereby stresses the importance of geography and selfishness to the extension of political power in Europe and minimizes the effects of individual statesmen, military leaders, and state policy in the expansion of political power.

Finally, we note some possible future refinements of the model. One could incorporate a more nuanced specification of geographic attributes of the European continent, including rivers. One might include a specification of the evolution of military technology and take into consideration increasing economic differentiation over time. The power function $P(A, C)$ could be specified in a manner that would better reflect economic forces and variables. In addition, game-theoretic considerations could be used to capture strategic behavior, possibly allowing for the appearance of new countries. These improvements would entail a large increase in complexity and the number of variables that may or may not produce more accurate results.

Our goal, however, was to extract the essence of a complicated system and examine whether its main features can be explained through a few simple rules, variables, and parameters. Our aim was not to build a complicated model but to test a simple hypothesis: Can a parsimonious model demonstrate the importance of predatory forces and the risks of overextension in the formation of the European state system over the centuries? Although a successful simulation model cannot prove that a particular historical process was at work, the maps in figures 4a–4c graphically show that a very simple model can indeed replicate with surprising accuracy the "grand sweep of history." This demonstrates at the very least the plausibility of our hypothesis.  

NOTES

The authors would like to thank Dr. Xuefeng Li of Loyola University, New Orleans (where the research initiated), and Christian Wagner of the University of Pau in France, for their help with the computer programming. Christian Wagner made the program available on the Internet.

1. This point was recognized by such eighteenth-century cameralist advisers of the monarch as Joseph von Sonnenfels (1777).
2. W. McNeill (1982) suggested, for instance, that the optimal size of an empire in antiquity was limited to about ninety days' march from the capital.

3. Armies could plunder along the way, and newly won territories did provide revenue; but if they were to be incorporated into the conquering polity, these regions ultimately had to be administered from the center as well (McNeill 1982).

4. The eastern border of Europe is unclear. We have attempted several variations, without substantially changing the outcome of the exercise.

5. For an analysis that considers the economic basis of military power, see Kennedy (1987).

6. Therefore, if a country has $n_1$ units of land border and $n_2$ units of coastal border, its perimeter is calculated as $n_1 + n_2$, as opposed to $n_1 + n_2$.

7. Tax on trade is not considered in this model.

8. In the sequel, for simplicity we will refer to $P(A, C)$ as the power function.

9. Even though $A$ generally increases like the square of $C$, the two variables are not independent.

10. In the sequel, for simplicity we will use the terms country or state interchangeably for the political units that make up the map of Europe.

11. This is done by using a random number generator to pick a unit square at random from the map of Europe with equal probability for each square. The country to which this unit square belongs will be $X_i$, which ensures that any country is chosen with a probability proportional to its size. This specification implies that larger countries go to war more often than smaller ones.

12. "Thus a prince should have no other object, nor any other thought, nor take anything else as his art but the art of war and its orders and commands." (Machiavelli [1532] 1985, 58).

13. Note that only the ratio of the powers $P(A, C)$ of two different countries is used. Therefore $P(A, C)$ is defined up to a multiplicative constant: multiplying the functions $P(A, C)$ by a constant does not change the outcome. In the context of rent-seeking, and conflict literatures, slightly different functional forms are used for the CSF, but they all share the same characteristic: they are equal to .5 when $P_A = P_C$ and increase beyond .5 when $P_A$ becomes larger than $P_C$ (Skaferdas 1992, 1995).

14. This is the case initially when countries have the same power, so the probability of any country's winning is .5 in the early stages.

15. In an expanded version of the model, $K$ could vary with time to account for changes in technology of warfare.

16. The program takes about ten minutes to run, with a rapid change of the borders at the beginning because the political units are small and the calculations fast. As countries increase in size, the calculations of the areas and perimeters become longer, thus slowing down the program.

17. The notion of maximum power can be defined only when a particular shape is specified, such as the assumption of square countries underlying the power function $P^*(x)$. A maximum power can also be defined if a country is shaped as a circle. Of course, the model yields countries that are not square. At the end of the simulation, for example, the two countries most closely resembling France and Spain have areas and perimeters of 446 and 120.1 for the former and 421 and 110.6 for the latter. These values, which show that the countries are far from square, yield powers of 2.35 and 3.09, respectively (equation [11]). We note that Spain's power is larger than France's even though it is smaller. The explanation is that Spain's smaller perimeter (which tends to increase power) more than outweighs its smaller area (which decreases power). In any event, the two countries have comparable powers by the year 1800 and have been at a rough equilibrium for a couple of centuries.

18. One important characteristic—and oversimplification—of the model is that the number of countries can only decrease, because there is no mechanism for the reappearance of countries once they have been absorbed by a predatory neighbor.

19. Please note that the model is programmed in FORTRAN on a workstation with an X-Terminal. The graPHIGS software is used to create the dynamically changing borders of Europe in color on the screen while the program is running.

The computer program and the color maps at one-hundred-year intervals are available on the Internet. For more details, go to http://www.univ-pau.fr/ser/CURS/MATHEMATIQUES/eurosim.html; this address is case-sensitive. E-mail address of first author: marc.artzroum@univ-pau.fr

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