The Fractal Dimension of the Coastline as a Determinant of Western Leadership in Science and Technology

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Summary: This paper argues that the fractal dimension of the Western European coastline was an important causal factor behind the continent's tremendous success in science and technology over the last centuries. The nicely articulated coastline fostered the political and economic developments necessary for science to flourish. These political and economic conditions of scientific progress are briefly outlined here. The fractal dimension is used as a mean to precisely quantify the coastline's degree of articulation. Measurements are made in the 100 to 1000km range. Western Europe's coastline is shown to have a significantly higher fractal dimension than those of the Middle East, India and China.

1 Introduction

Why did Western Europe succeed scientifically the way it did during the last centuries? And why didn't other civilizations? Why was modern science and the industrial revolution invented by the West? I shall argue in this paper that the causality chain leading to the European scientific "miracle" started with the high fractal dimension of the Western European coastline.

The Western part of the European continent is the only densely populated area on Earth boasting as many peninsulas, gulfs, straits, inland seas, while still being for the most part an interconnected land.

Such an articulated coastline enhances trade, because sea accessibility makes maritime transportation easier. The sea route is much better than river or land transportation. It is tremendously cheaper, it is less limited in capacity and enjoys more freedom. Before modern times, it was even faster. Thus a high level of coastline articulation, by bringing the sea closer to all places, allowed an economy to thrive in the long-term.

An articulated coastline defines naturally limited core areas (peninsulas, half-peninsulas, islands) within which polities can live their lives without being too much disturbed, as the sea is the best possible boundary for a state. Britain, Spain, France, Denmark, Sweden are such ancient states, well delimited by the sea. The shape of the

Western European coastline helped the continent to remain divided between stable and long-lasting states.

Thus the Western European coastline shape most probably enhanced economic growth and fostered the continent's stable states system. We shall argue that this political and economic background was the necessary and sufficient condition for the flourishing of science.

2 A Political and Economic Theory of Scientific Progress

A rich economy allows scientific and technical progresses in many ways: It generates a surplus, necessary for science and the arts to thrive. Moreover, merchants, bankers and entrepreneurs are obsessively looking for accuracy, counting, number-using. When successful, they gradually impose their science-friendly mentality upon society. Even better: merchants, bankers and entrepreneurs have a vested interest in science and technology: they support developments in mathematics (accounting arithmetic, higher-degree equations for interest rate calculations, statistics for stock exchange trading and insurances, etc.). In the Middle Ages, they supported the development of clocks for measuring manufacturing and travelling times, of accurate maps for travelling, of astronomy for navigation, and of course of all sorts of technical devices, since increasing manufacturing productivity and decreasing transport costs brings profit.

Stable political division helps science and technology in many ways. It generates freedom. No center has a monopoly of power, no government can control everything. The diversity of legislations grants a much larger overall liberty to science. Suppressed in a given country, a scientist or a technician can look for shelter in another one (these effects were already identified by various authors authors, like [1] and [2]). But there is more. Competition between states generates a profitable stimulation. Every government wants to do better (or at least not worse) than neighbouring countries. Hence governmental support for science academies. War exercices a continuous pressure towards modernization, it creates a strong government interest for new technical devices and for improving technical knowledge and education. But unfettered war wreaks havoc, thus the need for stable political division.

The same holds for the smart European scientific professional structure, universities, royal academies, private schools of mathematics. The institutions that allowed scientists to make a living while doing research could come to life only thanks to the good economic and political situation of Western Europe. When studying their history, it is easy to verify that these institutions thrived because of the possibility to flee to a another state, the availability of financial means, inter-state prestige and military rivalry.

Hence, we may formulate a general rule: in a given region (we should look at a complete region – a region mainly isolated from major outside influences –, i.e a civilization earlier, and the world nowadays), science and technology can advance if and only if the region hosts *a rich and stable states system*. Western Europe enjoyed a growing trade and manufacturing, and was divided between long-lasting competitive kingdoms during the whole 2nd millenium; this is why it succeeded the way it did. Other civilizations did not form rich and stable states system during as long a period as Europe, that is why, on the whole, they had less success.

3 Eastern Europe and Other Civilizations

The rich states system theory explains quite well the different stages of the scientific evolutions of Western Europe, Eastern Europe, Middle-East, India and China. As I showed in *Le Secret de l'Occident* [3], each time prosperity and stable division are there, science flourishes. Conversely, when other conditions are rife, like political unity, fast-changing boundaries, civil wars and/or economic doldrums, science recedes.

In particular, that theory sheds light upon the mysterious drop of Chinese scientific development around 1300: at this time, China departed from a "stable states system" state towards political unity. China did not enjoy favorable conditions again during centuries. It first entered unity, then suffered a civil war, then fell into unity again.

The difference between Western and Eastern Europe is neatly solved as well. The steadily weak performance of Eastern Europe in science and technology can be linked to the bad economic and political conditions which it suffered along the 2nd millenium. Eastern European states were unstable, they underwent fast boundary moves, they appeared and disappeared. Trade was weak, manufacturing rickety. Merchants never thrived half as well as their Western equivalents. This can be linked to the fact that Eastern Europe does not enjoy as good a shore profile as Western Europe: it is a mainly landlocked area. Vast surfaces are deprived of sea access: the seas are too far-away, they are often closed or ice-blocked seas. The vast land compactness explains why the economy remained sluggish (sea trade could not play a role) and why the region's states were brittle and short-lived (no natural boundary protected them).

4 Measuring Fractal Dimensions of Coastlines

4.1 Indices to assess a Coastline

The quality of a coastline (its degree of indentation) can be quantified with various indices, which we shall briefly compare here.

A very simple procedure is to measure the distance to the sea of the farthest point inland. This measurement, a first indication at best, gives the best note to Western Europe (see table).

Another, more elaborate, method consists in measuring the coast length and dividing it by the surface of enclosed land. This is the so-called "coastline development index". We display in the table below the results obtained by using shoreline measurements from Lucchini & Voelckel [4]. The development index sets Western Europe far above, at first rank.

The development index, however, is not a completely satisfying quantity because the length of the coastline is no definite quantity. A coastline actually is a fractal object, with no upper bound on its length. Comparison between development indices makes sense, to a limited extent, only so far as the coast lengths were measured at identical scales. The degree of articulation of the coastline is best measured by the fractal dimension.

4.2 Methodology

To measure coastlines fractal dimensions, we relied on the Richardson technique (see e.g. [5]), which originally inspired B. Mandelbrot in its exploratory work on fractals.

The length of the coastlines of Europe, the Middle East, India and China were measured on the map with a compas of an aperture of 1,000km. The compas approximated the shoreline with a broken line, whose length could be easily measured. The same operation was repeated with smaller and smaller segments. The segments varied between 1,000km and 100km.

The lengths of the broken lines were plotted versus segment lengths in a logarithmic-scale graph. The slope of the curve was taken as the fractal dimension. It was thus an "intermediary" fractal dimension, i.e. taken within a given segment range, and not the fractal dimension according to the mathematical definition, where one should look for the limit when segments shrink to zero, i.e. at the slope of the logarithmic curve in the graph at infinity.

The justification is the following: first, in a natural object like a coast, there is no guarantee that the slope of the logarithmic curve will converge to a defined limit. Second, when looking for factors impacting long-term history, we judge the 100-1000km range more relevant than, say, the millimeter or the micrometer range.

For each civilization, a start point and an end point were defined for the measuremnets on the map. The length of the broken line was defined as the number of entire steps plus the remaining length up to the end point.

The broken line follows the continental coastline. Islands receive separate broken lines as soon as they are large enough for the segment to "see" them. In such cases, a start and an end points have to be chosen for the island, introducing some arbitrariness in the process. To reduce this arbitrariness, we aimed at maximizing the measured length at each segment scale. Island coastline lengthes were added to the continental length.

Sometimes, the segment has the choice between two intersections on the map. For example, at the "heel" of Italy, the 316km segment sees both the Italian Adria coast and the Greek coast. In such cases, preference was given to the closest point along the coast, i.e. the one maximizing the final measured length.

An alternative calculating method to assess fractal dimensions would be to include terrestrial domain borders. These non-maritime border lines would be considered non-fractal, bringing a constant kilometer add-on on each shore length measurement. This approach would better mirror the impact of large terrestrial areas with little access to the sea, like Central Asia, which are not "seen" with a compas sticking to maritime borders. It would lower the final fractal dimension of terrestrial areas, yet increasing the Western European advantage.

4.3 Conventions

Be it for deriving fractal dimension, maximum distance to sea, or coastline development, the four regions to be compared (Europe, Middle East, India, China) were defined as follows:

"Western Europe" includes all territory west of the line Lubeck-Venice, with the Swedish-Norwegian peninsula added. "Western&Central Europe" contains all of European territory except the pre-1990 Soviet Union and Finland.

"The Middle East" was defined as Africa north of the Sahara, Arabia, Mesopotamia, Iran and Central Asia. The Southern limit was the Sahara desert

around present-day boundaries of Morocco, Algeria, Lybia and Egypt. The Northern limit was the Caucasus and Anatolia. Central Asia has only terrestrial limits. The starting point of the first coastline was in Southern Morocco, ending at the present-day Syrian-Turkish border. The second coastline was that of the southern Caspian sea. The third coastline started on the Sudanese coast and ended at the starting point of India.

"India" was defined as the whole Indian subcontinent. That includes present-day Pakistan, Republic of India, Bangladesh, Nepal, Bhutan, Sri Lanka, Maledives, Laccadives. The start point was near present-day border between Pakistan and Iran, on the west of the Indus delta. The end point was on the eastern side of the Gange delta, within present-day Bangladesh.

"China" was defined as the area populated by Han until around 1700. This includes the present People's republic of China without Manchuria, Inner Mongolia, Eastern Turkestan and Tibet. The coastline extended from Tianjin (harbour of Peking) down to the present Vietnamese border. Taiwan and Hainan were included.

The length of the coastlines was successively measured using 1000km, 316km, and 100km segments, so that the corresponding points were equally spaced in the logarithmic space. More segments can anyway be added inbetween if wished. A graph was built plotting increasing coastline length versus decreasing segment length. A best fit for the slope was obtained. This slope was dubbed the "intermediary fractal dimension" in the range 100-1000km.

5 Results and Conclusions

The results of different coastline measurements are displayed in the table below.

	Max. distance to the sea (km)	Development indice (10^{-5}km/km^2)	"Intermediary" fractal dimension
Western Europe	500	886	1.47
Western & Central Europe	800	702	1.42
Middle East	2,000	136	1.12
India	1,500	203	1.19
China	1,500	189	1.26

Table: quantifying the articulation/indentation of the coastline

The results clearly show that Western Europe has a much higher fractal dimension (1.47) than China (1.26), India (1.19) and the Middle East (1.12). These differences are significant because these figures can take values between 1 and 2, theoretically. Practically, they vary in an even narrower range. Indeed, a coastline with a fractal dimension as high as, say 1.8 or 1.9, is barely thinkable.

Thus, what is seen with the eye is confirmed by quantitative measurements. Western Europe boasts a much more articulated coastline than other civilizations. It has several large peninsulas (Spain, Italy, Denmark, Sweden-Norway), several islands more than 100km wide (Britain, Ireland, Iceland, Sicily, Sardinia, Corsica, Sjaelland, Gotland). Whereas the Middle East just has just nascent peninsulas (Tunis, Byrte) and no large island. India has only one peninsula (Gujarat) and one large island (Ceylon). China has only one peninsula (Shandong) and two islands (Taiwan, Hainan).

The intermediary fractal dimension tell the same story as other indices tested. Western Europe has a much more indented coastline than other civilizations. This geographical factor, through a complex chain of political and economic causalities, might have given Western Europe its edge in science and technology during the second millenium. Hence, although surprising at first sight, the European scientific "miracle" seems to be, indirectly, a present from geology.

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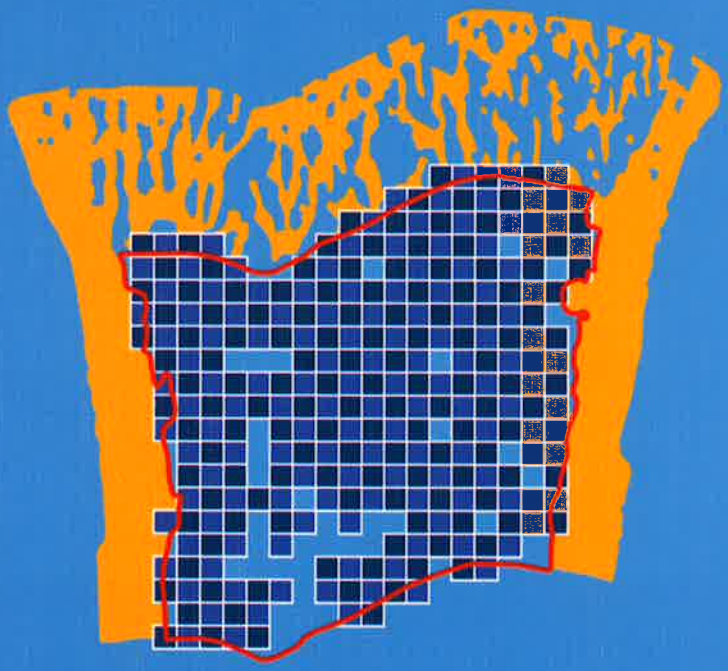

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