A Model for the *Polis*, the Ancient City-State

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Abstract

Polises are the ancient city-states that began to appear in the Mediterranean around 1000 BC. They were to be found not only in the area of ancient Greece, but also in Phoenicia and Etruria as well. These polises had different evolutionary paths and relationships with the sea.

The aim of the proposed model is to simulate these different paths by introducing cultural factors such as the "trade aptitude" and "conservative tendency" of the dominant classes and also by considering geographical constraints.

The model uses nine main state-variables, four concerning population and five the economy. Macro events such as emigration and/or expansion, which may generate a new polis, are explained in terms of social conflict between the two dominant classes: Lords and Emerging classes. The economic unit measure is yearly per capita consumption and the sampling interval is set to one year.

The model description also includes a comparison with Forrester's well-known *Urban Dynamics*. The reasons for the choice of the System Dynamics methodology are expounded in the paper.

Two running examples are discussed and shown as output plots. They deal with a case of high social stability due to sea trade activity of the Emerging class, and also with a case of low stability with generation of new polises.

In the authors' opinion, the model offers a general heuristic tool in historical analysis, but may also be useful for approaching present-day problems about the identification of a new development hypothesis for western civilization, in that it recognizes the fundamental role of cultural factors in addition to the economic ones.

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1. Introduction.

1.1. The reasons for looking back

The authors are mainly concerned with the application of Automatic Control Theory to shipping and activities at sea. However, following the first oil crisis we realized that technical problems of this kind cannot adequately be approached without a reference development hypothesis, i.e. the assessment of future scenarios in terms of civilization or, more specifically, of its socio-economic aspects.

Modeling the past offers advantages in adjusting the simulation tool because we are dealing with a known entity and, at certain times, the closed system under consideration is very small in comparison with the whole world. Hence it becomes easier to identify the functional structure and this can be useful in different space-time segments, including the future.

Such considerations generally hold true when considering activities at sea, because they benefit from a higher degree of functional "invariance" than on-shore ones, owing to the predominance of the physical environment. For example, the role of maritime power appears unchanged throughout the whole historical segment.

Interest in the *polis*[2], the ancient city-state, arose from the assessment of the future role and level of sea transportation and combat capabilities of the European Union (Grassia and Piattelli 1991). This interest is focused on the interaction between the polis and the sea, which gives rise to historically different evolutionary paths.

The modeling problem, described below, has the aim of simulating the various evolutionary paths. The model takes into account geographical scenarios and cultural characteristics and is b[illegible] on social stability as an evolutionary mechanism.

1.2. A look back at the historical scenario

Around 1000 BC, the inhabitants of the Phoenician city of Tyros (the modern Tyre) relocated their coastal town on nearby islands (Herm 1974). This is the zero time of our simulation. Colonization by Greek polises in the Mediterranean area occurs from 800 to 600 BC, a period that coincides with the golden age of the Etruscan polises and their expansion.

City-states were not a new phenomenon in the Mediterranean but around 1000 BC this way of life began to spread. This expansion was a consequence both of the evolution of local civilizations and of emigration from the older city-states.

This process may be explained by the exchange and communication made possible by the sea.

In any case, the city-state of this age, be it Phoenician, Greek or Etruscan (or even Rome itself), was to play a fundamental role in western civilization.

From 1000 to 500 BC, city-states were international powers that interacted on an equal basis. However, around the end of this period they were overwhelmed by the Persian Empire in the east and the Roman Empire in the west. The turning point in the east was marked by the naval battle of Salamis (480 BC), with the decline in the west following a few years later.

Nevertheless, for some five centuries the polises experienced a period of expansion and emigration due to the low degree of civilization along the scarcely populated Mediterranean coastline.

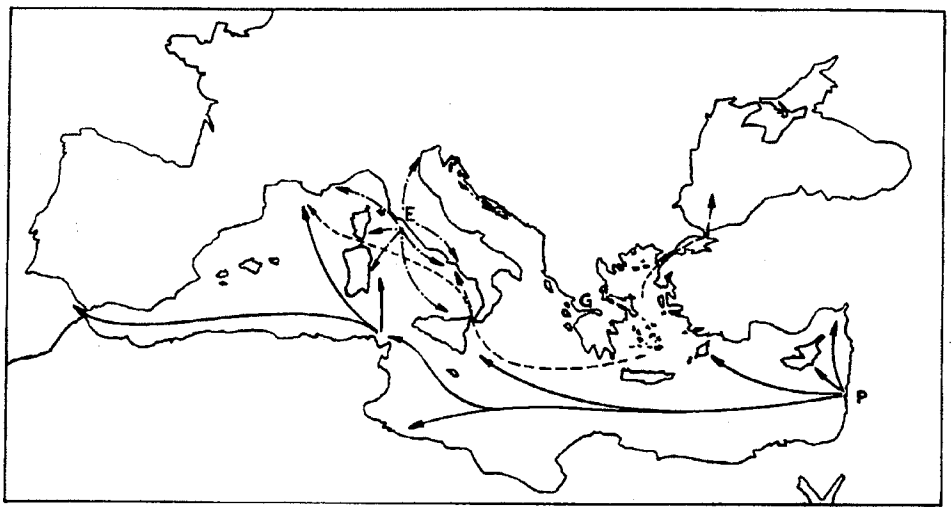

Fig. 1. Major directions of polis expansion.

Figure 1 shows the original areas of **G**reek, **P**hoenician and **E**truscan polises and the major directions of their expansion, mainly via the sea.

The process under consideration here is the generation of new city-states by the original ones. The proposed model is a conceptual interpretation of this process.

The model itself can be considered in two ways: from the point of view of System Dynamics methodology, as a tool for a particular theoretical problem; and from the historiographic point of view, as an explanation of well-known processes.

2 **Description of the model**

2.1 Comparison with Forrester's *Urban Dynamics*

A convenient way of introducing the model may be a comparison with Forrester's well-known *Urban Dynamics* (UD hereafter). Actually, both seek to be general theories of the city's long-term evolution. However, we chose to build the model from scratch, and not to adapt the polis behavior to UD as in the Zubrow's (1981) representation of ancient Rome, in order to include the particular elements we intend to investigate, such as the maritime milieu and the generation of new polises.

The six UD assumptions, quoted by Zubrow (ibid., 158), will be the guiding thread for the comparison.

The UD areal assumption maintains that the city is limited by its geographical boundaries. The urban area of the Polis and its countryside constitute a whole which is limited by unalterable boundaries.

The UD systemic assumption suggests that the urban area is an economic, social, ideological and geographic system. The Polis is a social-economic system, characterized by the invariant culture of dominant classes, set in a geographical scenario.

The UD distribution divides population, enterprise and housing into three separate categories on the basis of economic value. The Polis model does not consider housing; it divides population into four classes:

- Lords (I), who do not contribute to the wealth production;
- Farmers (R), who produce foods;
- Emerging class (EC), who are engaged in non-food production and trade;
- Slaves (S), who constitute labor, capital and also a means of trade.

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Enterprises are not considered. Production is assumed to be proportional to labor, deper ɜ, as consumption does, on previously produced wealth.

In conclusion there are nine main state-variables, coincidentally the same number as in the UD model.

The UD attractive assumption concerns houses availability and the labor exchange between urban and country areas. In the case of the Polis, the drift of labor from the country is simply caused by surplus food production or by saturation of productive land, which results in converting farmers into emerging class. The converse moves slaves from the city to the country, or more precisely from serving the Lords to food production.

The UD environment is limitless, i.e. capable of supplying or absorbing people and goods to and from the city without saturation. The Polis includes its own countryside, which is limited in the way of productive land and human capability; however its environment is assumed limitless for the exchange of food, goods and slaves, as in the UD assumption. In both cases, such an assumption simplifies the model by allowing the system to be treated as closed, because the environment is formed by infinite capacity, depicted with sources and sinks.

Finally, there is the UD assumption of non-competition between cities, which completes the closed-system hypothesis. The Polis model uses the same assumption in regarding war and trade, which are competitive activities, only in terms of internal effects that may be affected by random noise. In other words, in both cases it is the internal structure of the system that determines the city behavior, i.e. the dynamics is generated endogenously.

As above stated, UD and Polis models concern different processes. The former focuses on growth and stagnation of the urban area and does not seem to vary with starting conditions and scenario characteristics. The latter is dedicated to the production of internal instability in order to obtain macro events such as the generation of other polises.

A fundamental aspect common to both problems is that the origin of urban area and city-state is not considered.

2.2. Methodological Tools.

The implementation of models related to the "soft" sciences requires a specific tool. We have chosen the System Dynamics approach for the following reasons:

- it combines simplicity and rigor at the same time;
- the feedback loop representation fits our semi-closed system;
- the availability of conceptualization tools;
- its proven capacity of building simulation models for testing theories (Hanneman 1988) of almost every science[3];
- the methodology is easy to learn and the developed models are quickly understood even by scholars with a limited mathematical background.

The model has been developed with the MATLAB software package. A DYNAMO-like translation is available, provided both for comparison purposes and as documentation for users of this tool[4].

As in DYNAMO (Pugh 1983), the difference equation method has been adopted. In our simulation runs, the integration step, i.e. the sampling interval is set to one year and appears consistent considering that the system includes some parameters (such as food production, birth and death rate and so on) that are identifiable only yearly. In the ancient times, war and trade were also seasonal activities only. What's more, the difference equation mode allows the treatment of some different mechanisms, such as non-linearities, feedback, smoothing, delays, even without sound knowledge of these tools in terms of automatic control theory.

The significant aspects of the model remaining to be examined are summarized below.

2.3. General structure.

The simulation loop consists of four main subsystems:

- production and consumption, which produce the trade base,

- trade and war, which produce wealth,
- wealth distribution and use, which produce savings and social effects,
- population dynamics.

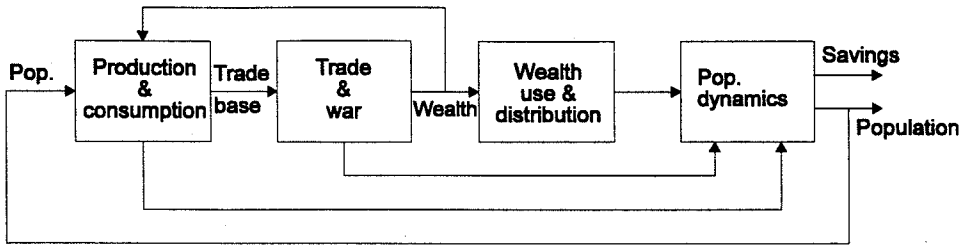

Fig. 2. Block diagram of the Polis subsystems.

Figure 2 shows a logical diagram of the model subsystems with the main functional connection. According to the automatic control-type block diagram, the line with arrows are variables and blocks are computations.

The cultural characteristics of the Polis, such as trade aptitude and the dominant classes' capacity for self-preservation, as well as the geographical constraints, are stated off-line.

2.4. The characterization table

Cultural parameters and geographical constraints define the Polis's character. Table 1 shows such parameters and their tentative values for four typical cases.

2.5 Economic dynamics, trade and war

Yearly per capita (YPC) starting consumption is assumed to be the economic gauge and corresponds to the minimum requirement of well being, which may be estimated as the current value of 365 grams of gold. Another fundamental value is the average cost of a slave and of its freeing. YPC food production is assumed to be about twice the base and YPC production of other commodities to be a little more, in order to obtain a system capable of producing wealth. Consumption and production indices change with the yearly produced wealth.

Slave productivity is less than that of free people, but the percentage of productive units is higher.

Production minus consumption is the trade base (see §2.3), but trade begins when a certain threshold is reached and its volume also depends on the available labor (of the emerging class). Profit changes with trade duration and war results.

War itself is a cost, both in the way of materials and loss of production due to the labor participation. War duration depends on trade duration; its intensity, expressed by the number of warriors involved, depends on the trade value. At least 400 warriors are required, which means a fleet of six *biremes* or *penteconters*[5], but their number can be increased to form a fleet of up to 75 *biremes* or more.

The effect of war on the population is given by the ensuing mortality.

War duration causes a certain number of battles (from 1 to 4) with a random result. Each victory increases trade profit whereas defeats reduce it.

The trade base multiplied by the factor computed by the trade and war result, minus war cost, gives the yearly wealth.

Yearly wealth is distributed among Lords, Emerging class and lord Slaves according to self-preservation capacity (from 1 of slaves to a minimum of 7 for Lords, see §2.4). Lords use half share of their wealth (or at least the same amount as their yearly consumption) in the activities of their role, that means a return also for the polis; the remaining value is converted into slaves and savings. If their share is insufficient, the difference is obtained from savings and the sale of slaves, and the

number of Lords decreases by a 7 years ramp. The same procedure is applied to the Emerging class share.

The Slave class utilizes savings for liberation.

In conclusion there are six economic state variables: savings held by Lords, by the Emerging class, and by lord Slaves; slaves belonging to Lords, to Farmers and to the Emerging class. The sum of the last three is also a population state variable.

Therefore equations are usually in terms of population or economic values, and this allows an easy dimensional consistency validation. When a time constant or ramp is used, a number of years appears as a divisor.

Table 1. Polis characterization

	Sparta	Athens	Tyros	Caere
Trade:				
duration (months)	2	2	6	6
threshold (1)	0.55	0.4	0.3	0.25
way (2)	M+A	M	M	M+A
War duration (months) (3)	1.5	1.5	3.5	3.5
Self-preservation:				
Lords	50	30	50	50
Emerging Class	7	25	40	40
Lord Slaves	1	1	1	1
Productive land as max. labor (4)	10	4	2	20

Legenda:

(1) As multiplier of total yearly food consumption.
(2) M = Maritime, A = Ashore according to geographical and political conditions.
(3) Base value corresponding to the max. trade duration and before random noise.
(4) As multiplier of starting Labor for food production.

2.6. Population dynamics

The population dynamics is summarized in the Table 2.

Table 2. Population dynamics

		Classes			
		I	EC	R	S
Increasing Factors:					
	Birth Rate	H	M	L	L
	from I class		*(1)		Exp
	from EC class	*			Exp
	from R class		*(2) & (4)		Exp & (1)
	from S class		*(3)		
	Purchase from Foreign				*
Decreasing Factors:					
	Death Rate	M	M	M	M
	New Born	K & Exp	Exp	Exp	
	Lords activities[7]				*
	War[8]	*	*	*	
	Trade[9]		*		
	Class change	*	*	*	*
	Sale to Foreign				*
	Liberation				*
	Emigration[10]		*		*

Legenda:
I = Lord, EC = Emerging Class, R = Farmers, S = Slaves;
H = High, M = Medium, L = Low;
K = Killing, Exp = Exposition[6];
(1) = Poverty, (2) = Food Surplus, (3) = Freeing, (4) = Productive Land Limit
* = Possible change of class

3. Running examples

3.1 Generalities

For reasons of comparison, all cases are simulated with the same initial values and constraints, which in the following examples are: 2000 Lords, 7400 Farmers, 150 Emerging Class members, 950 slaves; the land production limit is established as 3 times the number of starting Farmers.

A 500-year evolution is shown. There is an initial transient due to the arbitrary initial values. The following period is characterized by the reaching of the productive land limit, signaled by the saturation of Farmers and their slaves.

3.2 A high social stability case.

The series of plots in Figure 3 in the Appendices concerns the case of a polis with high social stability due to the engagement of the Emerging class in maintaining the sea trade network. Instability does not occur owing to the mortality caused by such engagement. This case could represent the typical behavior of a Phoenician polis, such as Tyros.

The plots show the main state-variables (9 curve-charts) and the number of warriors, traders and navy *biremes* engaged.

3.3 A low social stability case.

The series of plots in Figure 4 concerns the opposite case, one of high social instability. It could represent the typical behavior of a Greek polis with merchant attitude, such as Athens.

The discontinuities or "saw tooth" pattern in certain state-variables signal an emigration event, i.e. a generation of a new polis or colony. The number of these events gauges the social instability of the mother-polis.

The comparison of the two cases reveals the higher combat and trade capability of the polis which is socially more stable.

4. Conclusions

4.1. Preliminary results

From historiographical sources, the authors of this paper have conceived the idea that the evolution of ancient city-states in the Mediterranean area could be explained by a general model, which should take into account cultural factors as well as geographical constraints.

Such a model implies a social conflict mechanism, which leads to expansion and/or emigration, and the possible generation of new city-states.

The model seems to be a suitable tool for understanding and simulating the evolution well known city-states, providing that the off-line parameters are tuned according to the historical data. In any case, the generation of a new polis is conceptually explained.

The simulation outputs give the naval component of maritime power, i.e. the number of vessels in the plots, which, however, is computed without considering progress in naval technology.

The merchant component of maritime power has not been taken into account as, at this stage, the lack of adequate information from the source makes quantifying more difficult than for the naval component.

The model contains one state variable, the value of the Polis (i.e. public savings), which is not described here because it is not relevant to the dynamics[11]. Its use is in historiographic validation.

4.2 Further steps.

The model has not yet been utilized as heuristic tool in historical analysis on a systematic basis. Collaboration with historians would help to improve the model itself[12].

However, the authors' interest has now shifted to a different aspect: the well-being of individuals seen as internal feedback within the model.

The model under consideration here implicitly takes this point into account. The Polis is made up of four different social classes and its evolution aims to improve general well-being, in the way of population level and savings.

The problem now is to rewrite the model by functionally detaching the objective dynamics from the cultural factors. The latter will be used as a filter for gauging well-being and producing the evolutionary feedback to maximize it.

The cultural factors are always treated as invariant and define the level of well-being and the modification for increasing it. In this way it might be possible to reproduce Forrester's results, after the identification of the cultural factors assumed by him for UD.

The attempt to maximize well-being does not aim to change the simulation results, which however may be changed all the same; the aim is to obtain a more general tool to be applied as a support in the sphere of modern decision making, at least in public administration.

5. Notes

0. The authors would like to thank R. Bono for his excellent software assistance.
1. *The Enclyclopædia. Britannica* states that the plural of *polis* is *poleis*; but we prefer *polises*(as in metropolises) for better common understanding.
2. As the word *polis is* frequently used throughout the text, we have ceased to put its in italics. When Polis is written with a capital letter, it refers to the model.
3. Their spectrum goes from economics (Schuster 1973, Low 1980) to psychology (Wegman 1977), passing through anthropology (Shantzis and Behrens 1973), philosophy of history (Torrealdea and Grana 1984), sociology of science (Sterman 1985), etc.
4. The Polis source code in both languages will be available at the Conference as files on diskette or as hard copy. Moreover, authors can be contacted directly at their institutional addresses or, more conveniently, via e-mail at **polis@ian.ge.cnr.it**.
5. War galleys with 50 oars and oarsmen and about 10 crew.
6. Exposition, namely the abandonment of infants, was applied mainly to new-born females and is explained as a balancing mechanism between males and females, as the latter were not affected by an equivalent level of risk. The property rights of Etruscan women could have a similar purpose, i.e. to maintain the family's social role in the case of male death.
7. The Lords' activities such as war and trade result in a certain level of slave mortality.
8. War involves the Lords population only as a ritual manifestation. It affects the Emerging and Farmer classes according to its extension, which stems from the level of trade. The basic parameters are 5% of deaths in the case of victory and 14% for defeat. The actual war duration depends on random noise, as does the victory/defeat sequence.
9. Trade is considered as an onshore or offshore activity outside the city-state, performed by the Emerging class only.
10. Emigration only involves the Emerging class and its Slaves, because social instability is explained by an increase in the Emerging class population compared to the number of Lords
11. According to System Dynamics terminology, it may be considered as a supplementary variable.
12. It could even be a good opportunity to enable historians to evaluate the systems thinking.

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7. Appendices

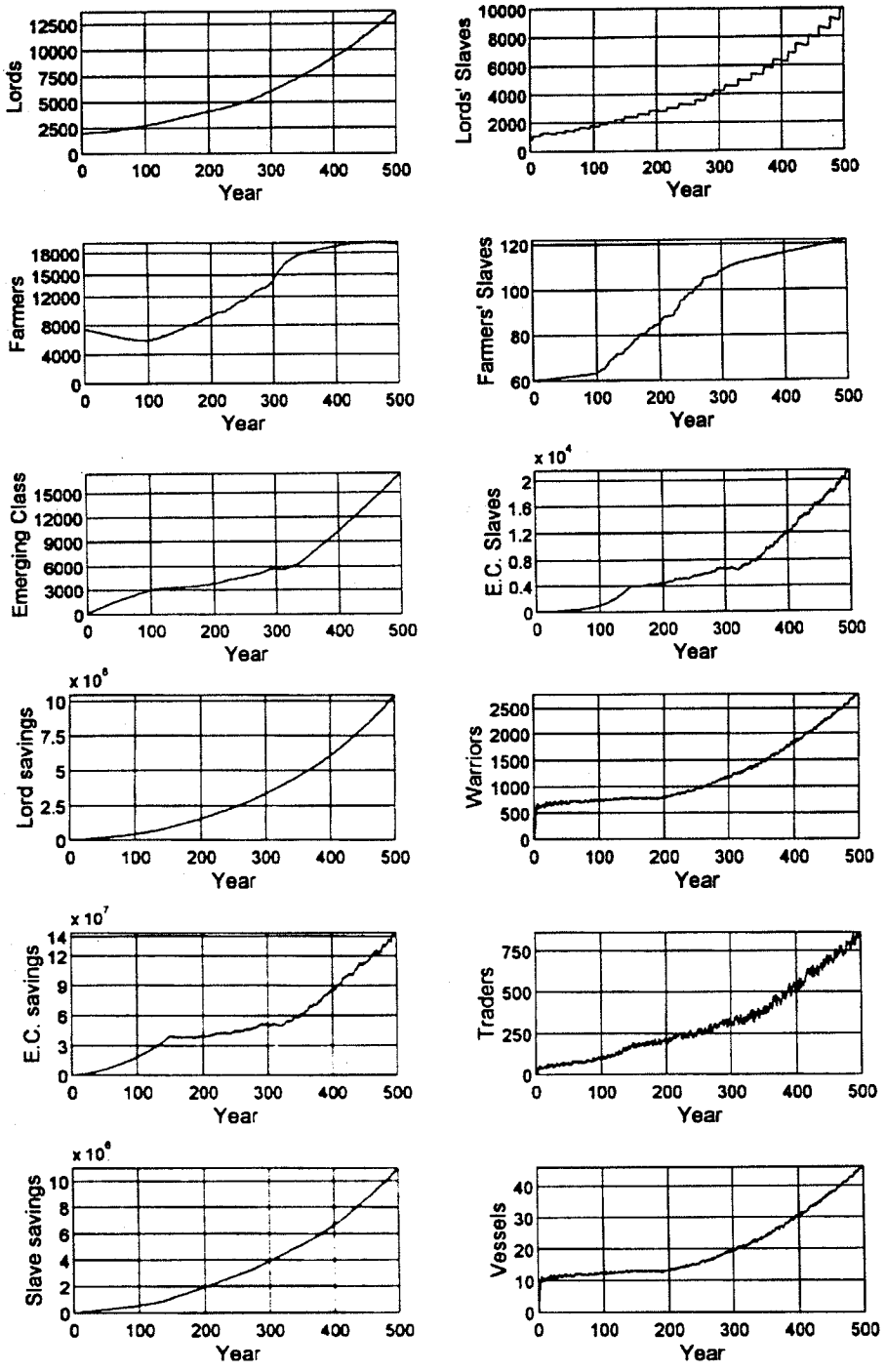

Fig. 3. Plots of the major variables of a polis with a high level of social stability

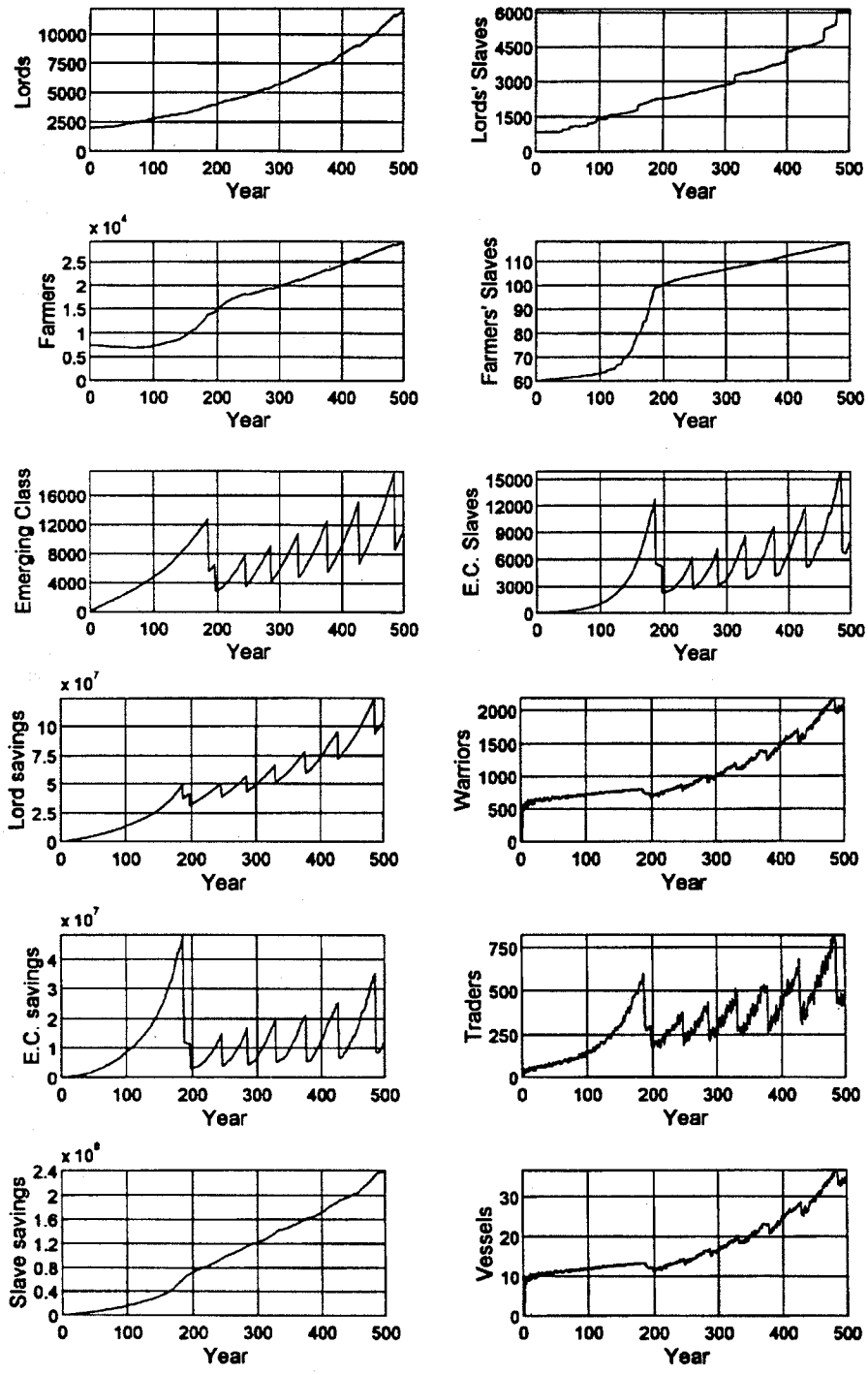

Fig. 4. Plots of the major variables of a polis with a low level of social stability. "Saw tooth" patterns mean generation of new polises.