Theory and Methodology

Entropy of plagues: A measure for assessing the loss of social cohesion due to epidemics

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Abstract We have asked the question what kind of illumination might be given to a series of historical events through the application of operations research techniques. The question is addressed by means of a model. In that model we compare the evidence for the collapse of civil authority during selected plagues of the 14th-17th century against the value for a casualty based entropy. The entropy is computed from time series of mortality data taken from the historical record of the selected period. This contribution builds upon previously published work in which entropy, computed from military casualties, becomes a predictor of combat outcome. The conjecture is advanced that mortality based entropy calculations reveal the impact of the plague mortality on societal structure. Comparison with. the worst of Dupaquier on the scaling of crises is made. Suggested extensions to additional societal phenomena are advanced.

Motivation

Societal structures are, arguably, among the most complex of systems. In this paper we shall put forward a suggestion for a simple and straightforward measure of damage to societal infra-structure. The concept explored is that of entropy. It is a gross measure at best, but like temperature and pressure for physical systems, we will be contending that a properly defined entropy may signal the onset of serious system impairment at damage levels of only a few percent of the components. In fact a case is to be made that systems are far more fragile than components unless specific design measures are taken to counteract loss of components. If, in fact, loss of a few percent of components signals serious degradation of system integrity, then this paper contains a warning message to civic officials and the models they depend on. It may be incorrect to label as alarmists those who contend that small percentages of infected constitute an epidemic:

or those **who** maintain that deferring more than a few percent of maintenance on infrastructure items like power grids or highways and bridges portends serious difficulty.

This paper examines the historical record of data from plagues. Certain of that data has over the past decade been the subject of intense re-examination and pruning, making it more amenable to the calculation of possible analytic measures of which entropy has been selected for this paper. Computation of entropy is embodied in a simple model which we shall shortly describe. However, that model uses data from a historical context with which the reader may not be familiar. We therefore make a short digression into the past with the goal of illuminating that history through the application of rather classical operations research techniques.

An historical preamble

During the Middle Ages society was periodically ravaged by waves of plagues which are today identified as the bubonic bacillus. Vectors for spread of the plague which are today identified as the bubonic bacillus. Vectors for spread of the plague were rats and infected people. Oddly enough the spread of the plague was not possible until communications and roadways reached sufficiently good working order to allow transmittal in less time than it took for the sickness to run its course. Even in terms of 20th century destruction, it is difficult to imagine the impact of mortalities ranging from a few percent to more than half the population. Lacking any comprehension whatsoever of the source, the plagues were usually viewed by the people as acts of a wrathful God. The period from the contractions of the disease to death might be from hours (pneumonic and especially septicemic) to days (bubonic). Responses to the impact on the societal structure of the time were both secular and spiritual. Among the lasting effects was the end of feudalism.

In this paper we will attempt via a simple model to quantify the eventual survival of societies in some selected locals for which 'scrubbed' data has recently become available. In order to understand the range of our selection we briefly describe some of the 'mechanics' of these plagues.

In terms of disease cycles we can detect two distinct movements:

(1) The 'Age of the Plague' beginning in the 14th century and continuing through the 15th and 16th centuries ending at last in the 17th century with sporadic occurrences in Southern Europe;

(2) the 'Age of social epidemics' lasting from the end of the 16th until the second half of the 17th century.

In the first period serious crises are a frequent occurrence. Every 10-20 years famine and disease gave rise to steep increases of mortality. Each cycle has a devastating effect and radically alters existing economic and social relationships. Although there were zones which were more susceptible: than others, as for example seaports which imported the disease from the Orient, every area suffered, even small rural villages.

From the second half of the 15th century crises due to plagues became less common, and in general less deadly, although authentic massacres still sporadically occur. They are consequences of the Black Plague which was pulmonary. Later the epidemics would become the relatively less deadly bubonic variety. In the first half of the 16th century the disease seems to disappear from a given region for 10 to 20 years, but reoccurs in violent and deadly outbreaks. From the end of the 16th century of the plague ceases to be the main demographic destroyer although in Mediterranean Europe its effect continues as before for more than a century.

We turn now to model considerations in an attempt to rapture the loss of cohesion brought about by the calamity of the plague cycles.

Model background

Carvalho-Rodrigues has introduced the idea of computing a Shannon style entropy (Hs) for simulating combat based on casualties (Carvalho Rodrigues, 1989). Thus,

$$Hs = -p.\ln(1/p)$$

where $p = C/N$ with C the number of casualties per side and N total number of combatants per side.

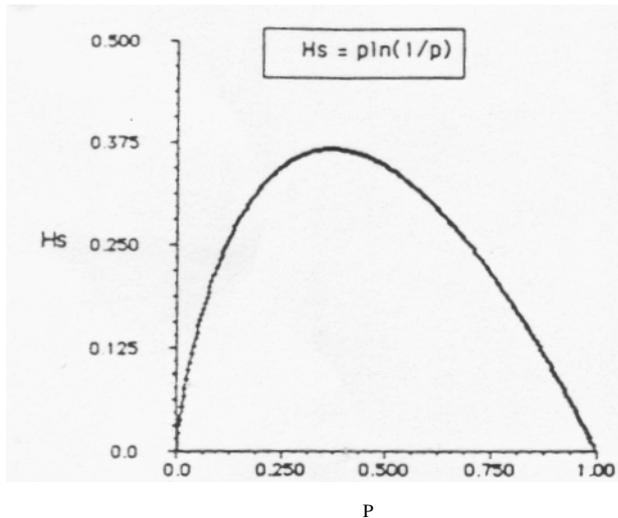Figure 1 illustrates the behavior of (1).

Figure 1. A graph showing the dependence of the entropy Hs on the value of the probability p

Carvalho-Rodrigues observed that the behavior of the curve in (1), which peaks at p = 1/e, more nearly matched the empirical evidence for the termination of battle in terms of percentage of casualties. Loss of the integrity of a force structure occurs at 10 to 20 percent casualty figures, for which values the entropy has already achieved 60 to 84 percent of its peak value. This essentially defines the term heavy casualties. The further use of an entropy, based on casualty figures, as a predictor of combat outcome was explored in depth by Carvalho-Rodrigues, Dockery and Woodcock (1991).

In the current contribution we propose an of casualty based entropy to study breakdowns in civil sector structure due to excessive mortality. With reference to (1), we identify C with the population loss in a selected period of time, and N with the population at the start of the period. Both a cumulative entropy and an interval entropy can be computed. In the first case N remains the same as C increases over the accumulating time intervals, while in the second instance N is redefined for the start of each . successive interval as is the value of C. Depending on the example, one or both entropies have been computed.

Methodology

In previous efforts the authors have identified entropy as a measurable quantity which is as basic to the understanding of complex systems as mass or charge is to physical objects. Like mass and charge it measures something about the systems as a whole without reference to details of the interacting components which comprise the system. Societal structures are examples of complex systems. When history is viewed as the interaction of complex and evolving systems, events can take on new meanings by mating use of the expanded vocabulary of systems science. Treated as evolving systems, the appearance of population centers can be expressed in terms of chaotic dynamics as mathematical attractors (Allen,1985). In the language of non-equt1brium thermodynamics, growing population centers are emergent structures. The concept of attractors is particularly instructive. It is more than a metaphor. In the work of Allen, some locales are natural attractors like harbors and crossroads. Others arise spontaneously. We argue that it is those centers, which arose because random events created an attractor, which were most at risk from the sudden rise in entropy resulting from the onset of a plague. They should tend to disappear from the history books, whereas population centers, located where natural attractors exist, could be expected to recover.

Wicken (1988) in discussing the subject of entropy introduces the idea of cohesive entropy. The senior author in work in preparation has also introduced an expression for the cohesion function (X), which is complimentary to entropy as expressed in (1) (Carvalho-Rodrigues, to appear):

$$\chi(N,C) = [\, H(N,C) / \Delta Hmax(N,C)] - 1$$

where

$$\Delta H(N,C) = \ln[1/(1- C/N)]$$

and

$$H(N, C) = H(p) = Hs$$

is as in (1). The condition for cohesion breakdown is *H(N, C) > ΔH(N,C)*. In this contribution we shall focus on computing and displaying *H(N, C)*.
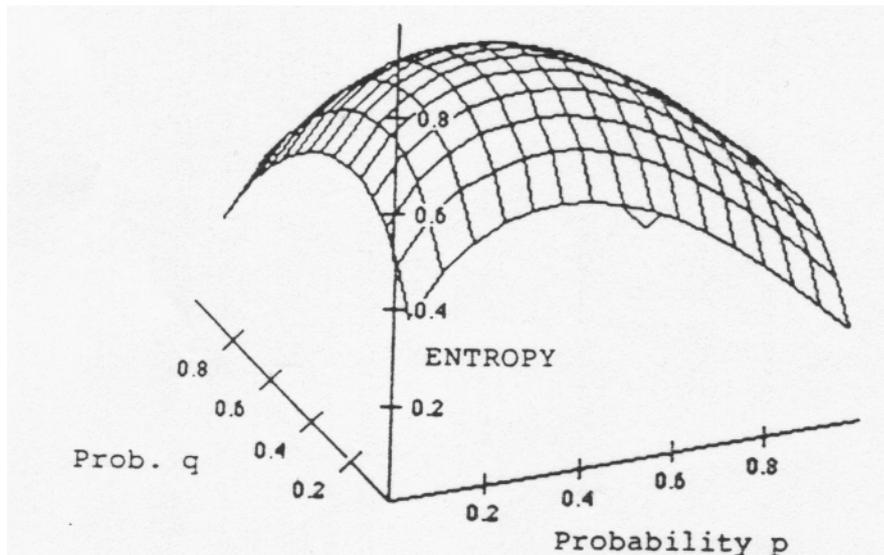
Figure 1. Surface plot showing the joint dependence of the entropy Hs on two probabilities, p and q

With the commentary of the previous paragraph in mind, we believe that the examples chosen provide additional insight into entropy as a measure of organizational breakdown. The operative term is now mortality, and the rate of morality must be such that the very structure of civilization itself is stressed. Any of the four horsemen of the Apocalypse[1] war, strife, famine or pestilence - provide such threats. Casualties in war we have previously treated. Besides, sometimes the purpose of war is to destroy the whole of the societal structure. Strife is not so readily quantifiable. Famine is a slow process - at least in the beginning. This leaves pestilence which strikes swiftly and is gone. Data on pestilence or plague in Europe near the end of the Medieval period is available in a number of detailed demographic studies (Anonymous, 1977; Alberola, 1985; Beribe 1984; Hollinsworth, 1969; Del Panta, 1986: Rodrigues, 1986, 1990; Slack, 1985). Examples were selected in which one could identify no other complicating factors. Had we chosen data complicated by the 30- and 100-years wars, we would have bad two or three major sources of entropy with war and/or famine being added to plague. When two or more sources of entropy are included, the curve in Figure I becomes a surface

as for example in Figure 2 where we plot

$$Hs = p. \ln(1/p) + q. \ln(1/q) \qquad (3)$$

where p, q are given by C_i/N_i with i = p, q and p+q = 1.

With additional complicating factors many communities simply ceased to exist with moralities from 60 to 90 percent. This is well beyond the peak in Figure 1, which occurs at a value for p around 37%. We recall again that loss of system integrity is postulated to occur for values beyond the peak. In addition we were looking for cumulative mortalities in the range of 5 to 35 percent for later comparison with the work of Dupaquier (1979).

Although the plague was endemic in Europe during the period studied, the examples chosen for analysis were primarily from southern Europe. That is because we had access to figures on population bases as well as mortality. Moreover, in the case to be presented from Lisbon, we have had additional access to the minutes of the city council meetings on health during the subject period (Lisbon municipal records, 1969).

Using the demographic data introduced above to compute a mortality based entropy, we felt justified in making a number of simplifying assumptions:

• To a first approximation the majority of the mortality for a short period of historical time

1 Revelations, 6: 1-8.

several weeks to a maximum of months - could reasonably be attributed to the plague. Where an entire region was involved, a short period can arguably be considered to be a decade or so. The average death rate component can safely be included in the total anyway since our hypothesis asserts that it is total mortality which causes the entropy to increase. Likewise the birth rate was ignored. Including it would tend to offset the average death rate. In any case we computed an entropy based on net population change.

• Loss of population due to flight, where flight was possible, e.g. city gates not locked and guarded, would inflate the mortality as we computed it from the population decline. We tried to select cases in which mass exodus was not reported. In any case we regard refugees as casualties of the epidemic with their absence contributing to overall societal breakdown as measured by the increase in entropy.

• The society affected was either static or in the process of new emergent structuring.

• The civil authority was very hierarchical, and the societies highly stratified. As plagues were not respectful of either rank or strata, excess mortality is assumed to permeate the entire society in question making entropy computation reflective of the entire system stress. Whether disintegration occurs is a race between the plague mortality increase and the decimation of the civil authority's ability to maintain infrastructure. Such eventualities are discussed by Slack (1985).

Examples

Five examples are presented. Each illustrates various combinations of time span and extent of physical locale. See Table 1.
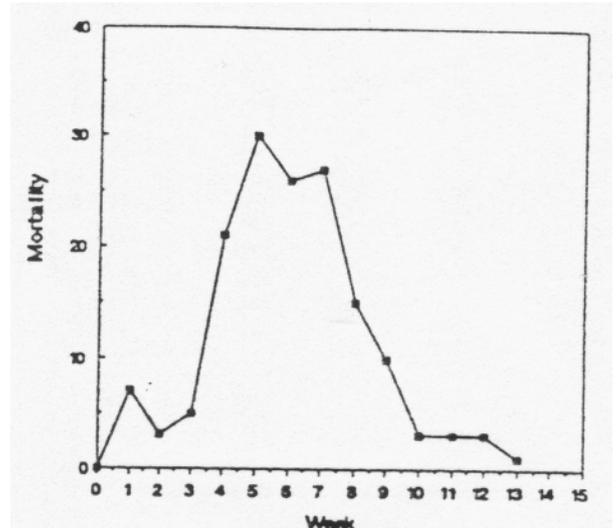
Castelo District of Lisbon-1569

Figure 3. Mortality data by week for the Castelo district of Lisbon during the plague of 1569

Lisbon, 1969

Our premier example is taken from records from the city of Lisbon, Portugal, in the year 1969. There are several reasons for this:

• The period studied is short, being only of 13 weeks duration.

. The documentation on the abdication of hierarchical control is excellent.

• The data can be localized by city district.

• At a point the city gates were closed.

In Figure 3 we present the mortality curve from the 13 weeks of the plague for the Castelo (Castle) district of Lisbon which is typical of the heavily affected districts. It was also the most influential neighborhood of the time. In the figure there is a sharp spike in mortality followed by a rapid decline.

Table 1

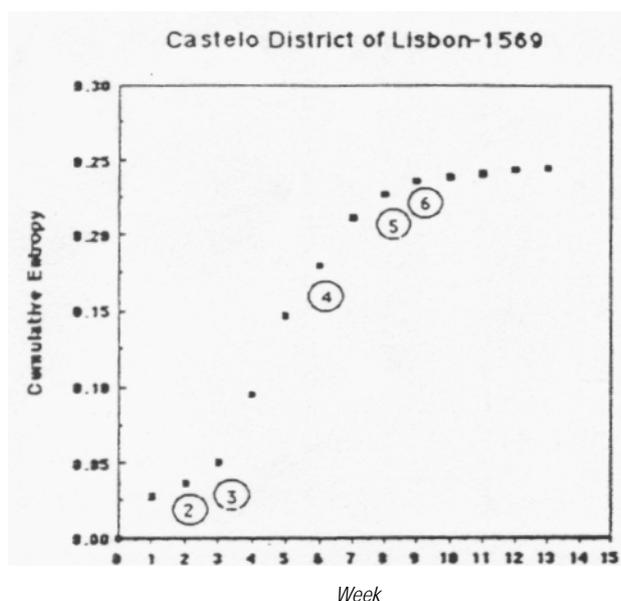| Locale	Description
Lisbon: 1969	Short time duration and delimited location
Florence: 1400	Longer time span and delimited location
Venice: 1630–31	Intermediate time duration and delimited location
Valleys of the Navarre: 1340–60	Long time span and extended locale
Valleys of the Estribare: 1280–1450	Very long time base and extended locale

Week

Figure 4. Cumulative entropy by week for the Castelo district
of Lisbon during the plague of 1569. Numbers in circles refer
to events of Table 2 of the tent

Converting the data in Figure 3 to a curve for
cumulative entropy, we obtain the results shown in
Figure 4. 1-he numbers in the circles refer to significant
events taken by the city fathers of Lisbon during the
course of the plague. They are taken from the actual
records of the time. They are of interest because they
chronicle the keys to Figure 4. In Figure 5 the
companion curve of cumulative entropy versus
probability is presented. It is also keyed to Table 2.

Examining Table 2, one is struck by the apparent

disparity in actions when compared with per
cent mortality as the criterion. It almost seems
like panic. Quite another picture emerges when
events are correlated with entropy production. L -
terms of depicting the seriousness of the predicament
faced by the Lisbon city council, it accords well with
their actions. We also observed that the plague rapidly
ran it course, and that the cumulative entropy did not
exceed 0.244 or 66 + % of maximum corresponding
to an 11 + % mortality in the district.

We have also computed the entropy of the Castelo
district by week. The result is displayed in Figure 6. It
follows the weekly mortality curve of course. Note the
correlation of the first spike in entropy and event
number 2 in Table 2.

In summary, history records that Lisbon recovered
swiftly but the entropy computation shows that it was
a close call.

Flounce, 1400

Florence in 1400 had about 60000 inhabitants when
plague struck with more ferocity than in our first
example. The mortality by month is shown in Figure 7
while in Figure 8 the corresponding cumulative
entropy by month is depicted.

Entropy rapidly reaches a level in excess of 0.30
but then flattens out as the death rate returns to normal
levels. It appears that entropy levels although high
permitted recovery of the city from the transient shock.

Table 2
Key events related to Lisbon plague of 1569

| Date	Week	Cum mortality (% of base)	Cum entropy (% of Max)	(No.) Event
Jun 26	0	0	0	(1) First reports of a plague
Jul 8	2	10 (0.7)	0.036 (9.8)	(2) Declaration of a plague
Jul 12	3	15 (1.1)	0.050 (13.6)	(3) Flight of the king – maximum delegation of authority
Aug 12	7	119 (8.6)	0.211 (57)	(4) First petition of the city fathers to leave the city – denied
Aug 28	9 .	144 (10.4)	0.235 (64)	(5) Second petition of the city fathers and their exit
Aug 30	10	147 (10.6)	0.238 (65)	(6) 'Martial Law' – City sealed
Jul 28,	52	–	–	(7) City gates reopened

Castelo District of Lisbon-1569
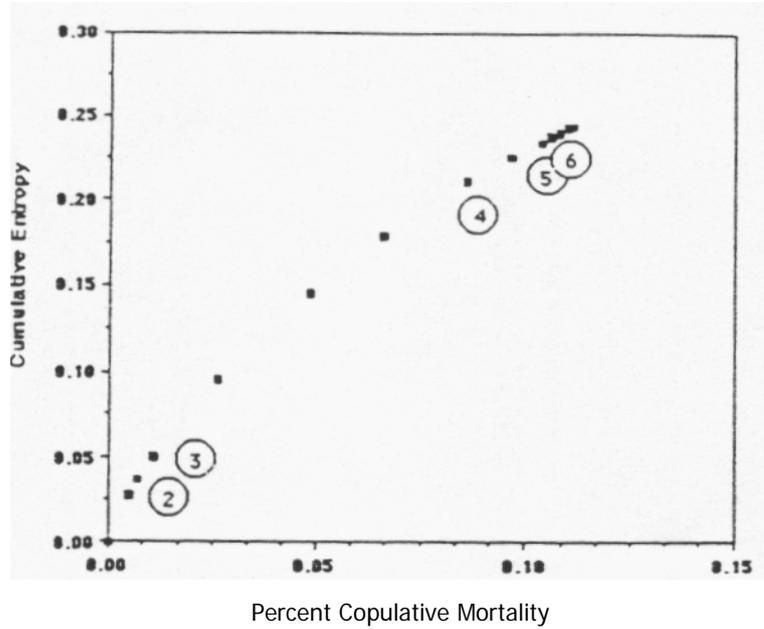
Figure 5. Cumulative entropy versus probability for the Castelo district of Lisbon during the plague of 1569. Numbers in circles refer to events of Table 2 of the text

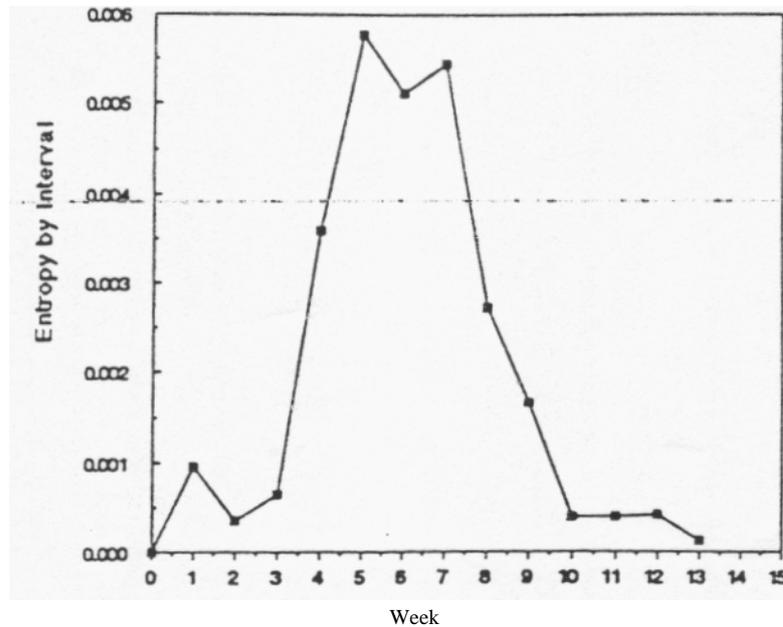Castelo District of Lisbon-1569

Figure 6. Entropy by weekly interval for the Castelo district of Lisbon during the plague of 1569
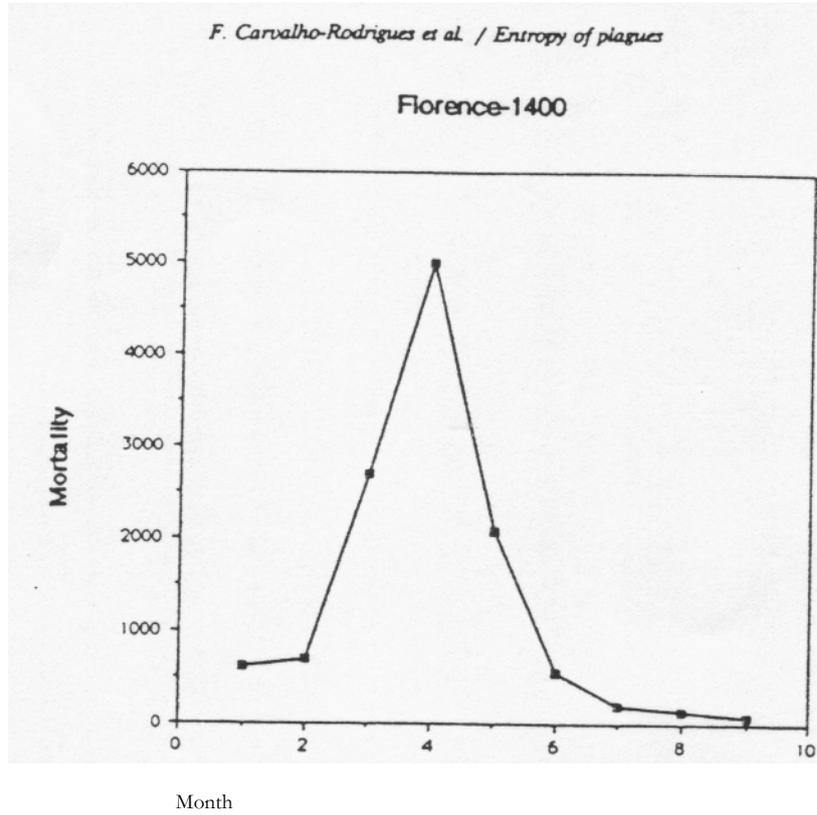
Florence-1400

Month

Figure 7. Mortality in Florence during a plague in 1400
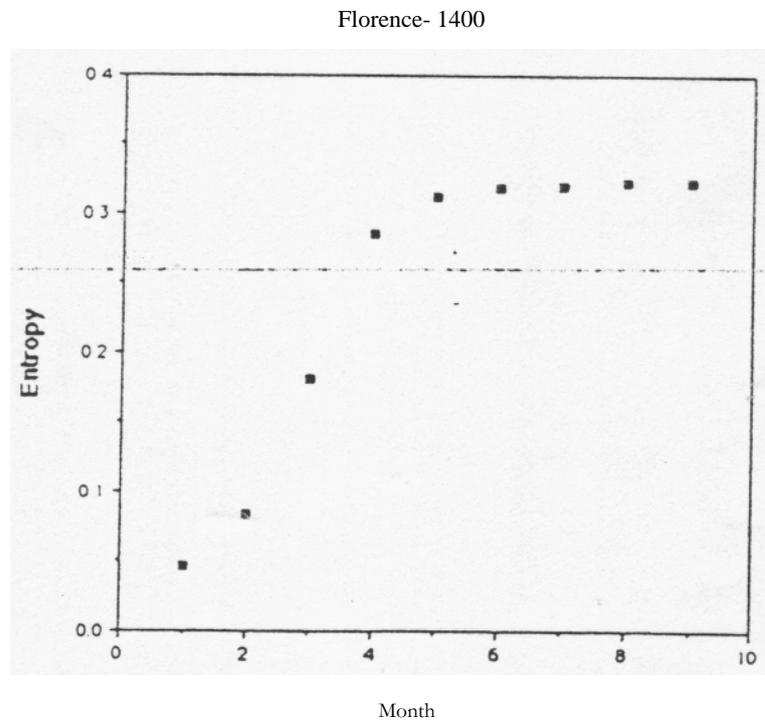
Florence- 1400

Month

Figure 8. Cumulative entropy by month during a plague in Florence in 1400

Venice, 1630-31

For the third example we chose the city of Venice. It was interesting because the entropy computation was inherently more difficult. Some reasons follow.

• The record covers fifteen months beginning in the July/August 1630 time frame.

• There were actually two episodes of plague during the period examined as can be seen in the mortality by month in Figure 9 with peaks in November 1630, and again in June 1631.

• Neglect of births and flight is potentially much more serious.

Lisbon in 1569 was but lightly touched by the plague incursion compared with Venice in the period 1630-31. Cumulative mortality reached 33%. In percentage terms it peaked in the fourth month at 10 + %, which is what the Castelo district of Lisbon sustained in total aver 13 weeks. More importantly Venice bad to contend with two plagues in succession. Figures 10 and 11 both display two curves. One corresponds to using the population base of 141000 for all 15 months. The second assumes the start of the second infection about the eight month.
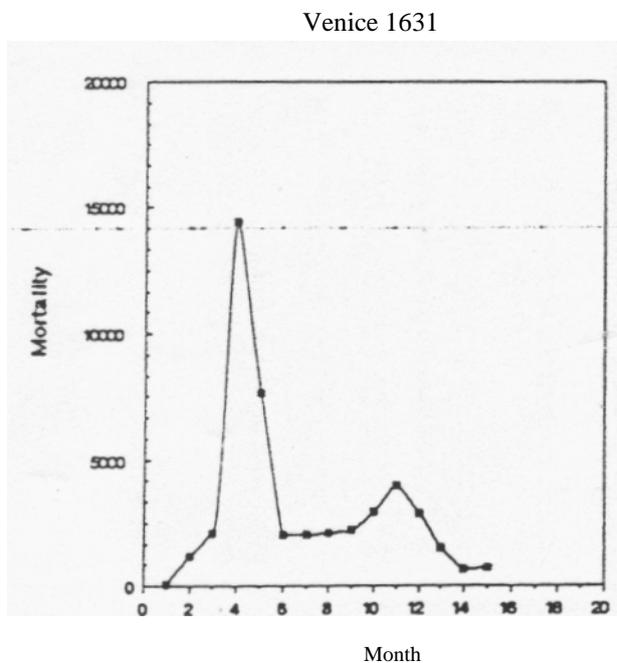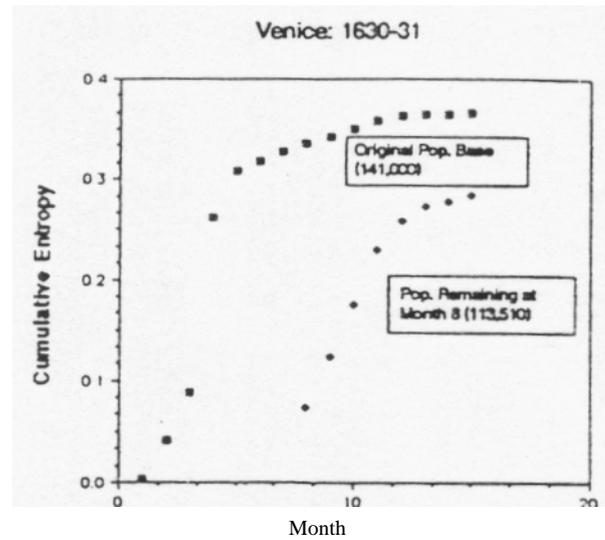

Figure 10. Mortality by month in Venice during the plague of 1630-31. The second curve treats the second plague as an independent calamity starting in the eight month

If the city had achieved anything approaching stability after the first round, that stability was short-lived. From the standpoint of entropy as a measure of gross changes in a complex system, it would seem that the second plague delivered a knockout punch to the city. The peak in the fourth month pushed the entropy to 0.26 indicating severe system stress. By the eight month :he cumulative entropy stood at 0.34. By month eleven when the second plague peaked, the cumulative entropy bad reached 036. By our hypothesis these values indicate probable disintegration of the original structure, and (sometimes) the emergence of new structure. But, as the original entropy curve was flattening out, the second curve was rising sharply toward a cumulative value of 0.28. These levels would stress a well organized structure. What they did to Venice is contained in the historical record. It took decades for the city to recover. That it did recover eventually may be due to its location and importance where a natural harbor could be viewed in the language of emergent strictures as an attractor for continuing commerce.

The Valleys of the Navarre mid Estribare

Navarre. If Venice and Lisbon recovered from the onslaught of the plague, we now present curves for two locations which did not. These are

Figure 9. Mortality by month in Venice during the plague of 1630-31
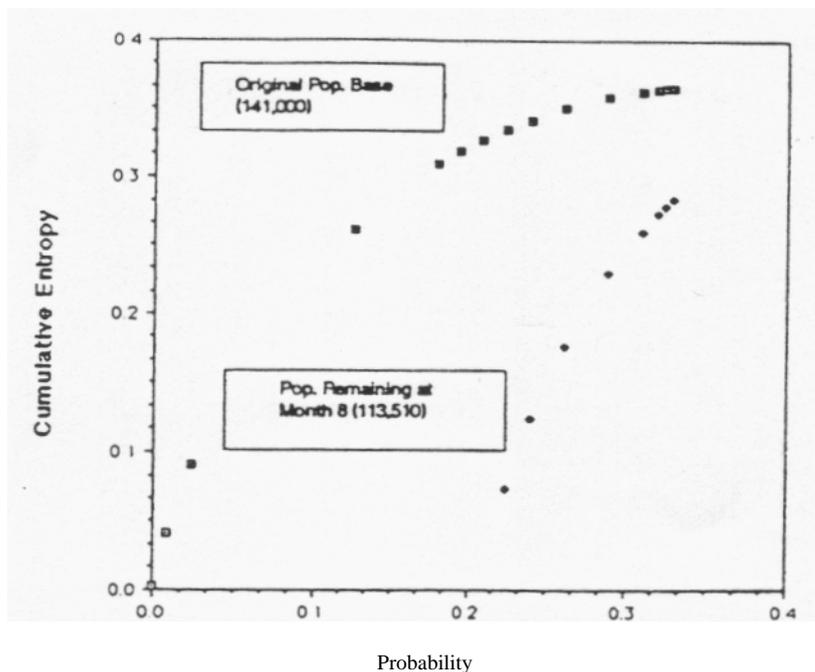
Venice 1630-31

Probability

Figure 11. Cumulative entropy for Venice during the plague of 1630-31. The *second curve* treats the second plague as an independent calamity starting in the eight month

the valleys of the Navarre and Estribare regions of Northern Spain respectively. They were chosen for at least two reasons:

• There are good records.

• The catastrophe is distributed over a geographic region.

Our time interval now shifts to decades. Around 1340 a cluster of valleys of Navarre, then an independent kingdom, showed evidence of becoming urbanized. Between 1340 and 1360 plague befell this region. Figure 12 shows the population story for the valleys, sorted on increasing size in 1340, compared with the same group in 1360. We have computed the entropy for each valley based on the twenty-year decline in population and display that in Figure 13. Virtually all the locales are past the peak of the entropy curve indicating collapse of the complex system The historical records show that this area went into decline and never realized the potential of the incipient urbanization.

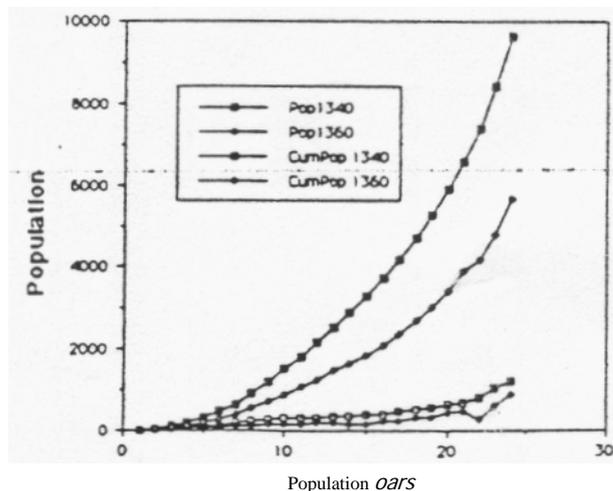*Valleys of the* Navarre

Population *oars*

Figure 12 Population summary for the valleys of the Navarre in 1340 and 1360 showing both individual and cumulative populations for 1340 and 1360. (Sorted arbitrarily on increasing size)
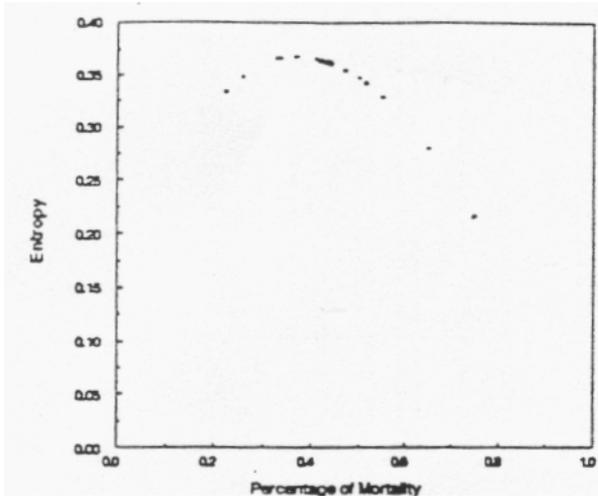
Valleys of the Navarra Region

Figure 13. Entropy computed on population decline for the valleys of the Navarre between 1340-1360
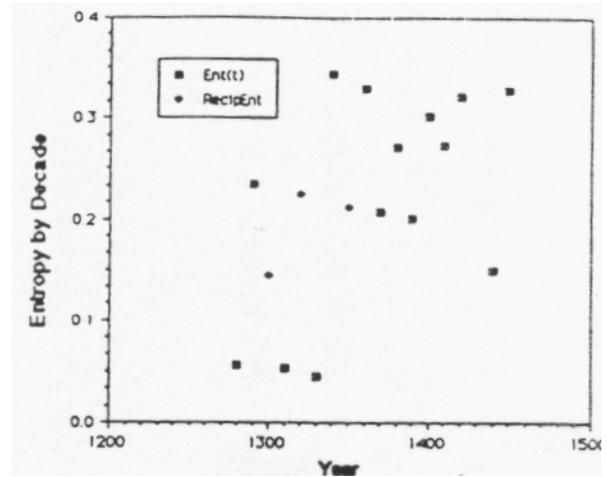
Valleys of the Estribare

Figure 15. Entropy computed by decade for the valleys of the Estribare region. Squares represent decades when population fell. Diamonds represent decades of growth computed by using a reciprocal entropy based on ln(1-p) - see text

Estribare. From Figure 14 we see that around 1280 a region called Estribare (Spain) was showing dramatic population increases. Then, in the interval from 1340 to 1350, plague swept through. There was recovery and again plague around 1360-70. This time there is no recovery. By 1430 the area is again stable but depopulated and
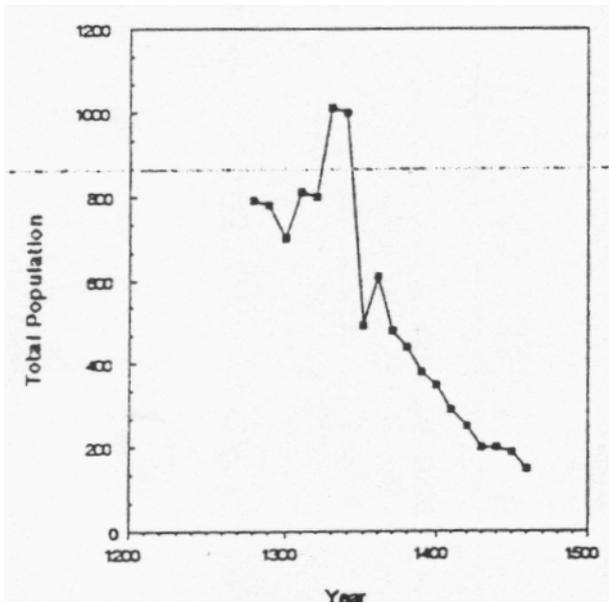
Valleys in Estribare Region

Figure 14. Total population by decade for the valleys in the Estribare region of Spain

presumably rural. Figure 15 shows the same period but from the standpoint of entropy change by decade. Periods of growth were computed by first computing the percentage change and then computing

$(1 - p)\ln [1/(1 - p)]$.

Both clusters of valleys might be characterized as examples of spontaneous urbanization already introduced. Lacking a natural attractor random events did not conspire a second time to produce urbanization.

The rest of Europe

- With but five selected examples we-can-only introduce what we consider to be an intriguing parameter by which to study disasters that stress the fabric of a society. When entropy reaches numbers that close in on 037, our naive hypothesis indicates probable collapse. When recovery occurs instead, one could look for reasons in terms of natural attractors. In the same time span (1630-31) that we used for Venice, the city of Verona incurred an aggregated decline in population from 189432 to 93212, or a difference of 96220 (5l36). In entropy terms this amounts to a value of H equal to 0344. Yet by 16722, the population had recovered to near pre-plague levels of 162031 from whence it grew only slowly, standing at 183629 by 1710. Entropy is a blunt

Table 3
Crisis scale (after Dupaquier)

Scale of crisis	Description of crisis	Magnitude scale	Percent mortality
1	Weak ('mineure')	1-2	
2	Average ('moyenne')	2-4	
3	Important ('forte')	4-8	
4	Major ('majeure')	8-16	
5	Super	16-32	≈ 10
6	Catastrophe	> 32	≈ 20

tool and cannot explain the foregoing dynamics, but it does require that a search be made for the underlying dynamics because, roughly speaking, recovery was swift

In fact we have looked at some fifteen cities in Northern Italy and the region of the Po river in terms of mortality for the plague of 1630. A plot of entropy versus percentage of cumulative mortality is shown in Figure 16.

Most of the localities experienced such large percentage mortality that the entropy is on the wrong side of 37%'0. History records that this region was indeed devastated. What re-emerged was a new structure

What of the rest of Europe? It is observed that the plagues did indeed result in the appearance of new societal structures as feudalism waned all over Europe. We might suggest that a more systematic comparison of plague induced entropy and emergence of new structure, although well beyond the scope of this paper, is in order.

Comparisons with Dupaquier

Dupaquier has developed a scale for rating civil disasters. He develops a kind of `Richter scale' for civil disruption stemming from crises due to the incidence of mortality in a subject population. The scale has been adopted by other demographers. It is reproduced below in Table 3 with percent mortality taken ham his discussions of various disasters of scale 5 and 6. We believe that it might be interesting to compare the scale with the entropy curve, and then infer mortalities for scales 1-4.

In Figure 17 a possible corresponding is displayed. Based on the observations to date we would agree that the mortalities for crisis scales
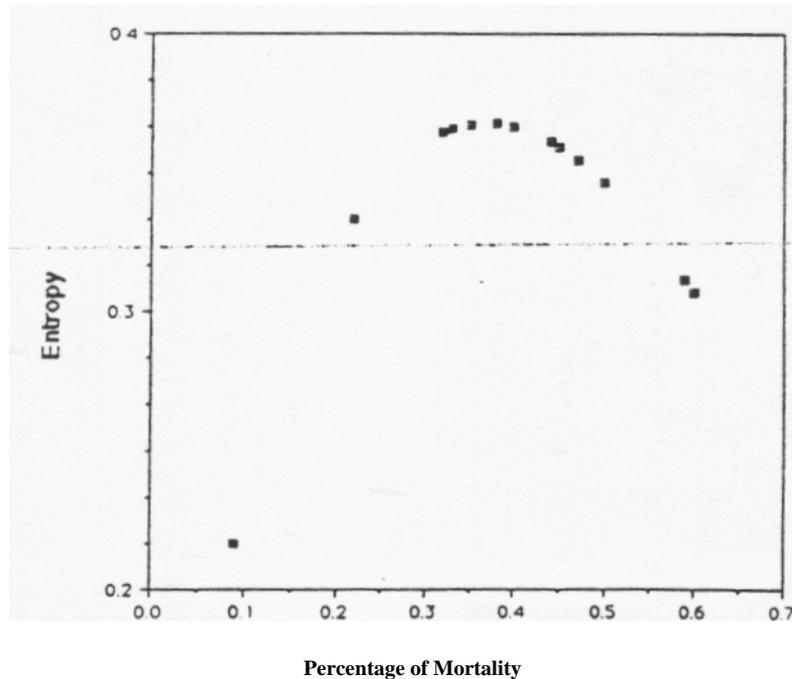
No. Italy & Po Region - 1630

Figure 16. Entropy for fifteen locations in Northern Italy and the Po river region during the plague of 1630
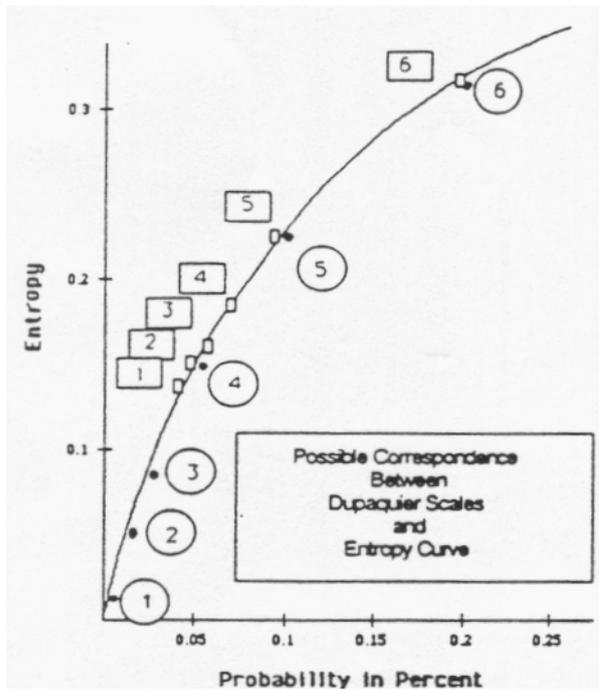
Figure 17. Possible correspondence between Dupaquier crises scales and entropy. Circles refer to case 1. and squares to case 2, in Table *4*

approximately by the small black circles.) What Dupaquier is doing with his scale is perhaps empirically mapping the steepest part of the entropy curve.

In approach number two the historian among us inferred a best guess range for percent mortalities from Dupaquier's discussions: they are depicted as open squares in Figure 17. Surprisingly enough, there is some overlap between the rather mindless first approach (circles), and this second one (squares). However, the definition of level 4 of approach (case) 1 is shifted down to level 2 of approach (case) 2

Table 4 contains the more precise values for entropy. The last column also contains the entropy values as a percentage of maximum of the entropy curve (36.8°6). This column is probably most representative of the scale of the crisis. In fact moving the catastrophe level to the maximum would permit one .to rescale by dividing by 32 to get the lowest level crisis equal to the range 1.15 to 23 percent. The curve is so steep here that one would have to iterate extensively to get a base value. In fact the steepness of the curve indicates to us that Dupaquier' makes fine distinctions between weak and average crises that cannot be substantiated in terms of entropy. The problem with approach 2 is that it fails to map the early part of the curve.

Comparison is invited between Figure 17 and Figure 4, which shows the response of the Lisbon city council.

and 6 (10 and 20 percent respectively) do in fact correspond to catastrophes of major proportions. In order to complete the comparison we needed values for mortality for scales 1-4. Two approaches suggested themselves.

In the first instance we explored simple ratios. In order to generate the percent mortality we have, therefore, liberally (and literally) interpreted the column 'magnitude of the scale'. This means we halved the percent mortality for each successively smaller crises starting with 5 and 6, which we find in the literature. Numbers in the small circles in Figure 17 refer to the scale of the crises. (The location on the curve is shown

Extensions and speculations

What is magic about 37%?

If 37% seems to be the point at which one structure dissolves, it also seems to be the point

Table 4 - Proposed correspondence between Dupaquier crisis scale and entropy

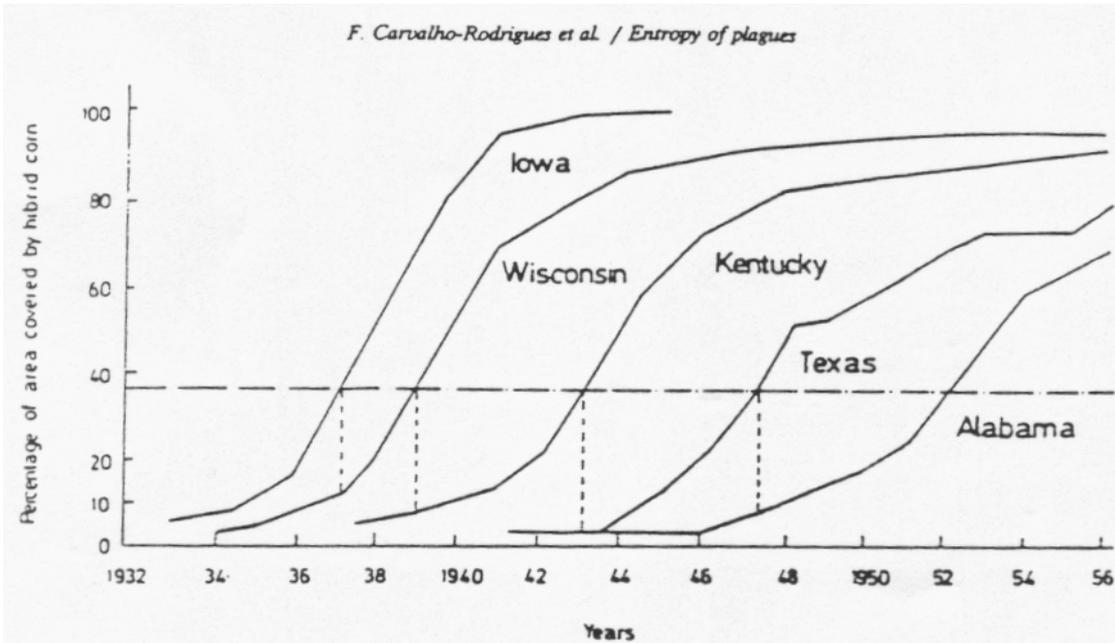| Scale of crisis	Percent mortality		Entropy value & (Percent of max)		
	Case 1	Case 2	Case 1	Case 2	
1	0.625	4.2–5.0	0.0317 (8.6)	0.143–0.15	(39.0–40.6)
2	1.250	5.0–5.5	0.0547 (15)	0.15–0.16	(40.6–43.8)
3	2.5	5.5–7.0	0.092 (25)	0.16–0.184	(43.8–50.0)
4	5.0	7.0–10	0.15 (40)	0.184–0.23	(50.0–62.5)
5	10.0	10–20	0.231 (63)	0.23–0.32	(62.5–87.5)
6	20.0	> 20	0.322 (88)	> 0.322	(> 87.5)

Figure 18. Rate of diffusion of hybrid corn showing the correlations to emergent structure in the form of diffusion of the technology. (Modified after Coombs et &1(1987))

at which a new structure makes its appearance. Just how far can this speculation be pushed without seeing entropy behind every change? Actually quite far if entropy is truly a global property of complex systems!

As a case in point we have cursorily examined in a thoroughly heuristic fashion, the complicated subject of technology transfer by relying heavily on the work of Marchetti (1980, 1985). In Figures 18 and 19 taken from Marchetti, the 1/e point is indicated on the curve showing the growth of a technology. Dropping down to the abscissa from the 1/ a intercept corresponds to one of two instances of new structures In the first instance, which is hybrid corn in the USA, new structure corresponds to the spread of an existing technology (Coombs. Saviotti and Walsh, 1987). For the second case we find an old structure being supplanted by a new one in the form of fuels or modes of transport.

market? It is presumed to be driven by so many different agenda that no particular relevant feature emerges. If entropy is truly a global parameter for complex systems, it should be possible to

Figure 19. (a) (Top). Switch points from one fuel base to the next showing the correlation of 1/e to the newly emergent structure using the new fuel (Modified after Marchetti (1980, 1985).
(b) (Bottom) The switch points in modes of travel showing the correlation of 1/e to the newly emergent structure using the new transportation mode. (Modified after Marchetti (1980, 1985))

Entropy and the invisible hand

We have been careful in both the previously investigated military example, and in the choice of plague data by choosing cases in which there is asserted to be one relevant factor from which to compute entropy. But what of the complex system existing in say the market place, e.g. stock-,
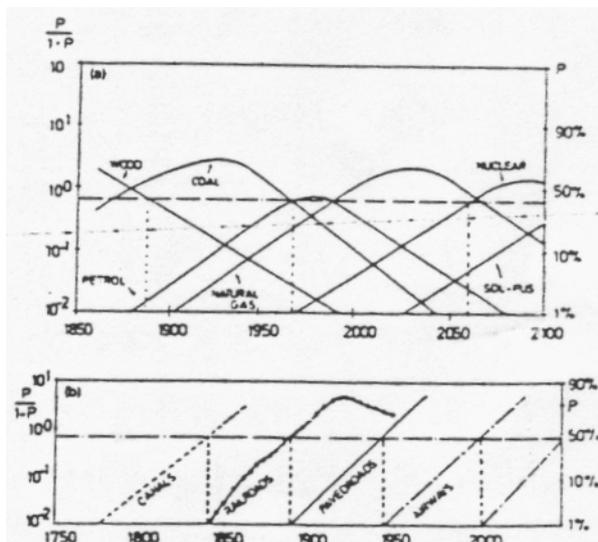
compute an entropy but we do not yet known how. Perhaps what is required for an entropy calculation to work is to introduce system parameters which are not dependent upon the many agendas but rather record the sum total of these interactions, e.g. MI, M2 and M3, in a manner not unlike pressure, temperature, and volume.

Relevance to the modern world

The use of entropy with its suggestion of radical social restructuring at 1/e, and the stress represented by a rapid rise to a peak value of 37%, should yield new insight into what constitutes tolerable disruptions to stability. Although this work is based on relatively large mortality figures, the use of entropy can perhaps point the way to assessing the impact of low intensity conflict on stability of civil government.

Summary and conclusion

We have presented examples of entropy (H) computed from dramatic declines in population associated with plagues of the Middle Ages. Disruptions approaching values of H=0.37 indicate serious breakdown of the societal structure. This is in accord with our previous investigations of entropy as a combat outcome predictor- An attempt was made to show that Dupaquier's scale of crises resulting from high mortality map the entropy curve, may in fact be a heuristic approximation to it. Finally we have speculated about other possible societal evidence that 37% is the breakpoint for complex structures.

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