A Thermodynamic Framework for the Measurement of Stability in the International Political System.

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Abstract

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This paper specifies a heuristic framework fashioned from the principles of the Second Law of Thermodynamics intended to extend and broaden our explanation of the structural dynamics of change and transformation within the global political system. I begin by outlining the logic and principles of the Second Law of Thermodynamics, with particular attention to the forms of energy and the nature of entropy critical to evaluating structural integrity. From this, I link energy, structure, and entropy to the underlying logic of the stability and instability of the international political system. Specifically, this paper proposes and explains four forms of structural integrity that logically take shape within the international political system as a result of the natural combinations of information and scope prevailing across nation-states. Using T. R. Gurr's *Polity II* cross-national time series data drawn from 152 countries between 1800 and 1986, I present findings which confirm that salient patterns of structural stability within the global political system are consistent with our expectations based on the principles of thermodynamics.

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Introduction

Authority and structure are two of the most explored concepts in social science. At the core of authority is structure; the essence of structure is authority. Within society, authority finds its basic expression in the form of government. (Munro, p. 9) underscores this argument and alludes to the dangers of limiting our understanding of authority to specific political settings, when he asserts:

> "Surely there is an element of danger in a situation where our progress runs so fast in all the sciences except the one that ought to be the greatest. For although science may be the basis of civilization, government is the retaining wall that holds the entire structure in place".

Yet, without a deeper appreciation of the nature of structure and the rationale it provides authority, we run the very real risk of separating authority from its most basic component--energy. "Since everything that goes on in nature is a manifestation of energy in one form or another, there is no branch of knowledge that can be excluded from thermodynamics." (O'Bannon, p. 4) Thermodynamics is in its broadest sense the science of energy, and it is therefore to thermodynamics that we must turn if we are to achieve a deeper understanding of the inextricable bond that ties authority to structure through energy. If a political system can be conceptualized as consisting of its different forms of energy, then a thermodynamic analysis can be seen as an effective approach to evaluate the stability of the political system.

Contemporary events have pressed upon us the demand to both illuminate and apply this linkage between authority, energy and structure. During the past five years, the structure of global politics has been radically transformed. The collapse of communism, the rebirth of democratic principles within East Central Europe, Asia, Latin America, and Africa, and the sheer explosion in the numbers of new countries within the international system, have combined to compel intense scrutiny of the events and circumstances which have apparently shaped these changes. Unfortunately, much of this effort has focused on the immediate context within which nation-state transformations have taken shape. Time and space considerations have all too often been restricted to the immediate events and names central to the activities which appear as surface currents on the global political landscape. Lacking is a framework which can place these brilliant and often confusing changes into a broader perspective, and from which a sense of perspective and proportion can be better appreciated. More than ever, paradigms within one field of study seem inadequately equipped to confront the Herculean task of comprehending and simplifying the sheer scale of change encompassing the world today. The principles of thermodynamics, linked to the underlying logic of political authority and structure, hold out the possibility of an effective strategy designed to confront these restrictions.

This paper specifies a heuristic framework fashioned from the principles of the Second Law of Thermodynamics intended to extend and broaden our explanation of the structural dynamics of change and transformation within the global political system. I begin by outlining the logic and principles of the Second Law of Thermodynamics, with particular attention to the forms of energy and the nature of entropy critical to evaluating structural integrity. From this, we link energy, structure, and entropy to the underlying logic of the stability and instability of the international political system. Specifically, this paper proposes and explains four forms of *integrity* that logically take shape within the structure of the international political system as a result of the natural combinations of *information* and *scope* prevailing across nation-states. Using T. R. Gurr's *Polity II* cross-national time series data drawn from 152 countries between 1800 and 1986, I present findings which confirm that salient patterns of structural stability within the global political system are consistent with our expectations based on the principles of thermodynamics.

Principles of Energy

Thermodynamics: An Overview

The Second Law of Thermodynamics is often referred to as the supreme law due to its universal application. The second law is conceptually simple, stating that among all possible states of a system, one and only one stable equilibrium state exists. (Gyftopoulos and Beretta, p. 63) One consequence of the second law is *that the direction of change is always from a higher state of organization to a lower state*. In thermodynamics, the order of the system is measured by its entropy level, or measure of disorder. If through a thermodynamic logic, the basis for entropy and entropy production within a political system can be discovered, then one can effectively evaluate the conditions under which greater stability in the international system may be achieved.

In thermodynamics, as well as many other disciplines, we must begin first with an understanding of the system concept. A system refers to that collection of bodies upon which forces of energy act. In this paper, we may think of a system in a more narrow sense: a collection of interconnected bodies, such as the sovereign nation-states or polities, which compromise the international political system. Other systems could include a geographic region, or an individual political system, depending on the boundaries chosen for the unit of analysis. Thermodynamic systems are either *open* or *closed.* A closed system is characterized by the absence of energy flows across the system boundaries. Of the examples above, the only closed system is the international system. An open system allows for mass and energy flows across the system boundaries. A region or nation-state are examples of open systems.

Thermodynamic systems may be studied from a *microscopic* or a *macroscopic* point of view. The microscopic approach to thermodynamics is concerned directly with the structure of matter. It involves the position of atoms and molecules within a system, and the certainty of their position at any given time. This approach tends to deal with average behavior, statistically measured, which is then related to the aggregate behavior, which represents the macroscopic view of the system. The macroscopic approach deals with system characteristics and general properties of the system. The macroscopic approach is commonly referred to as *classical* thermodynamics. (Moran and Shapiro, pp. 3-4)

An example of macroscopic versus microscopic logic would be water vapor or any other gas in a cylinder being compressed by a piston. The microscopic view looks at the positions, interactions, and reactions of the atoms or molecules of gas involved in the system. The macroscopic view is concerned with the overall pressure, volume, temperature, and physical state of the substance being compressed. The heuristic framework developed within this paper relies upon the two principle types of energy within a political system: *information* and *scope*. From these two types of energy, we can clarify the basic tendencies inherent at the "microscopic" level of the political system. Relying upon the principles of microscopic systems logic, we will develop a macroscopic framework to explore the pattern of authority and structure across the international political system.

Energy

Energy is defined as the capacity to do work or to transfer heat. It can be manifested and transformed into various forms such as heat, electrical, and mechanical energy. The total amount of energy in the universe, according to the *First Law of Thermodynamics*, is constant. Energy can be further classified into three forms: *kinetic*, *potential*, and *internal*. Total energy within a given system is the sum of these three components. (Moran and Shapiro, p. 42)

Kinetic energy is an extensive property (a property of the body as a whole) and is characterized by the motion of the system. The faster the system moves or the greater the mass of the system in motion, the greater the kinetic energy. If a system--or body-- is accelerated by a force, the work done on the system is transferred energy and is manifested as greater kinetic energy. Kinetic energy is a manifestation of a dynamic, or interacting system.

Potential energy is an extensive property. In nature, it is the energy a system--or body--possesses due to its position with respect to the earth. A system--or body--has potential energy when the system--or body--is at a height greater than its surroundings and can take advantage of the gravitational pull of the earth, and it is therefore an attribute of both the body and the earth. Energy can be transformed back and forth between its potential and kinetic form. An example is when a tennis ball is held above the ground and then dropped and allowed to bounce. When the ball is being held, it holds 100% potential energy. As it begins to fall, the potential energy is converted into kinetic energy which reaches a maximum the instant before the ball strikes the ground. When the ball begins to bounce back up it is regaining some of its potential energy as it loses kinetic energy to gravity and air friction forces. The system (the tennis ball *and* earth) does incur energy loss during impact and flight, and this loss is a manifestation of *entropy*, which we will consider later.

The *internal energy* of a body is the sum of the microscopic types of internal energies contained in the system. This form of energy may be potential or kinetic. The composition (e. g., bond energy in a chemical reaction) of a system determines the amount of internal *potential* energy which can be used to do work. A good example of this is coal, which when burned is transformed into thermal energy. An example of internal *kinetic* energy, which is an intensive property (i. e., it may vary from place to place within the system), is found when a gas in a closed, insulated vessel, is stirred and the gas molecules begin to move. Kinetic internal energy can be the translational, rotational, or vibrating movement of the gas molecules. As the system comes back to equilibrium the kinetic energy decreases again.

Information

The energy which drives a political system is *information*. Information are bundles of data which are interpreted contextually by a body with respect to the particular system to which the body is attached. Time, affect, and distance are critical parameters for information within a system. Each will be discussed below. What gives information the effect of energy is its specific systemic context. Absent this context, the effect of force on other bodies within the system is minimal. Structure, therefore--or the arrangement of bodies within a system--depends upon information. Structure takes its shape through information; the more coherent the information, the more coherent the structure. A political system may be defined by its utilization of information and the structure it incorporates to handle the information. This paper will demonstrate that the distribution of information, when combined with the scope is fundamental to the stability of a political system. We must first draw out this complex relationship between information, structure and systems.

Information is the first of the two critical energy-like entities. The free three-dimensional flow of information (from government to constituent, constituent to government, and constituent to constituent) is the energy which drives the democracy, and the controlled one-dimensional flow of information (from government to constituent) is the energy which supports the dictatorship. Information can take on several forms of energy, existing as potential and kinetic, as well as internal energy. It will also be seen that the ramifications of information can be decided by time, affect, and distance.

If information is analogous to energy, than it is important for the total amount of information in the universe to be constant (First Law of Thermodynamics). From this it follows that information can be both kinetic and potential energy. Information has its greatest potential energy when no one contains it. This can be seen as a scientific principle or idea that has not been discovered yet. When someone obtains a bit of information for the first time, the information has some kinetic energy but is still overwhelmingly potential energy. As this person diffuses the information to others the information loses potential energy in its original form and gains kinetic energy. This principle is reflected by Bagehot (p. 167), when he describes the very nature of human discourse. Referring to discussions among people, Bagehot notes once a person submits a information through verbal communication, "...you can never withdraw it again; you can never again clothe it with mystery, or fence it by consecration; it remains for ever open to free choice, and exposed to profane deliberation."

It is important to note the original form of the information due to the different interpretations each person may have. In the application of the actual information transactions in the political system it is the interpretation of the information transmitted to the human brain which is important. In other words, contextual interpretation of information transforms structure. Information may maintain its original form in a text where it will not change, but is still subject to different interpretations upon the reading of the text. Information in a book is also a form of potential energy and until everyone has that information it retains some potential energy with which it can still affect someone. (Mueller, p. 96)

The potential significance of information is also affected by the medium of its transmission. Specifically, speed of transmission constrains the overall impact of information upon a system. Information has a larger potential to impact society if it can be given to all people at the same *time* (television, radio, newspapers). It can have a much larger impact on society and a political system if the information is distributed as a concentrated (impact) force as opposed to a distributed load with respect to time. Thus, information reaches a maximum kinetic energy at the moment it is transmitted simultaneously to everyone. Due to this relationship, time helps define the ramifications of information.

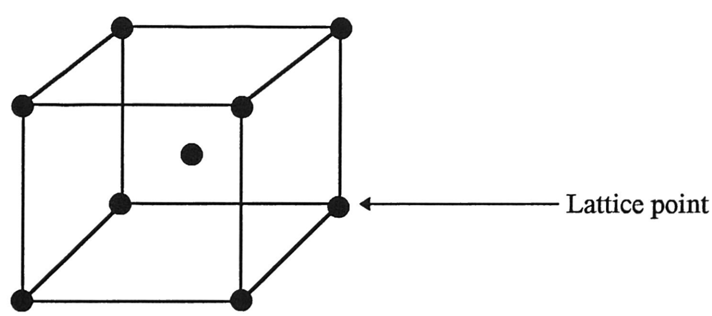
Information contained by a person is internal energy on the microscopic level. Just as the movement of the molecules of a gas in a chamber is internal energy in a physical sense, the effect of information on the interpretive process of the brain is analogous to the effect of internal energy on a political system. Deciphered information affects behavior. Thus, the more important the information is, or the more *affect* felt due to the information, the greater the impact of the information on the structure of the political system. Affect is the result of a stimulus (i.e. information). Affect is the emotional force acting on a person's attitudinal disposition toward some stimuli, or information. It is important to realize that the information has a larger chance of causing affect if it is personalized for the individual. Some types of information transmissions are more personalized than others (those which allow a one to one correspondence) and thus the type of technology used to transfer the information is important. For instance, on the Internet an individual may go to cyber sites which contain the information which is important to himself/herself. This does not mean that other forms of communication cannot be just as important to an individual (mass media in particular), but are less likely to be personalized. This form of energy is truly microscopic as personalized information often moves individuals and small groups in directions opposite of the society as a whole.

The ramifications of information, especially within a political system, can also be decided by *distance*. The closer two people are, the quicker the information may be transferred, and the greater the impact of the information. The closer the parties involved, the greater the chance of obtaining a maximum kinetic energy and the greater the force which may be applied to one side or the other. As important political information is transferred to a citizen, the potential impact of the citizens reaction is defined by the distance between the citizen and the government representative. The lesser the distance between the two, the greater an impact the citizen may have immediately on the government. This becomes especially important with technology which allows the citizen to become effectively closer to government, regardless of physical distance, such as e-mail messages, faxes, and telephone calls. In today's modern world, it is important for the political system to be equipped to handle the large numbers of information transactions as well as the decreasing distance between constituent and representative.

Scope

In order for a physical object to exist, it must contain some *binding energy*. In a physical material, bond energy holds each individual atom in a lattice structure which characterizes the substance. An example of a lattice structure, the body-centered cubic lattice structure, is shown in Figure 1 below. (Askeland, 42)

Figure 1 - Body-centered cubic lattice structure.



In the physical world, structure is dependent upon energy , and energy itself shapes structure only through its interaction with matter. The forces and reactions that govern matter are constrained by the physical laws of the universe, such as Newton's law. In effect, these physical laws that give meaning to energy are equivalent to authority within the social and political system of man. Authority within the social and political systems requires a well defined social context within which roles of individuals are defined by a particular structure (i. e., institutionalized interaction between two or more roles). Governmental authority is one form of authority within the political system. It regulates the interactions of subordinates and superordinates within a defined geo-political space. The principle property of this authority is *scope*, or the degree to which superordinates in their role as representatives and agents of the public direct and constrain the activities, choices and behavior of the public. (Gurr, p. 21)

Following this reasoning, it can be assumed that for a political system to sustain its structure over time and space, a sufficient degree of scope must be present in order to deal with energy (i. e., information) flux. This further suggests that as the scope of a political system increases, the directions and restrictions placed upon the actors in the political system are increased. With respect to the lattice structure analogy, scope is the bond energy holding the structure, or political system, together. Scope limits the movement of factions within a political system just as bond energy limits the movement of atoms in the lattice structure.

Similar to the various types and strengths of different lattice structures, there are varying levels of scope which also bring different characteristics to a political system. Just as in a physical mass, overloading a system with energy will generate stress on the structure. In materials science, it is often seen that the stronger the material, or the more tensile force required to fracture the specimen, the more brittle the material. In general those materials with lower tensile strengths exhibit more ductility. *By this logic, more force is necessary to break the brittle, high scope political system, than is required to break a ductile, low scope political system. Accordingly, it is the polities with the stronger lattice structure and binding energy, or scope, which are more* *likely to fracture instead of deform.*

By the mathematical definition of information explained in the information theory originally put forth by Claude Shannon in the 1940s, *information builds structure*. In a political system, this information is presented to its citizens as scope. Information in this sense can be seen as an effectual symbolic communication within a defined spatial environment. Scope provides a basis and framework for the individual to take in and deal with information. By Shannon's logic, a greater stability can be achieved when government imparts greater scope. However, it will be seen that when both diversity of information and scope, the two primary forms of political energy, are taken into account, there is a maximum level of scope that may be obtained without sacrificing a critical level of diversity in information flow in order to maintain stability.

Entropy

To summarize our discussion of structure to this point, three critical concepts have been introduced: energy, structure, and scope. Structure is institutionalized interaction between two bodies having a defined authority within a political system. Energy--or information-- is the means by which forces may be applied by one or both parties within a structure to affect the actions and behavior of each body. Scope is the extent of authority structure within a political system.

At the polar extreme from a system characterized by structure, is one characterized by entropy. Entropy is manifested as randomness, disorder, and inaccessible energy within a system.

In a physical body, the particles in a solid state are at a lower entropy state than those in a liquid state, and those at a liquid state are at a lower entropy than those particles in a gaseous state. In a solid, the particle may vibrate but is still attached by physical bonds to a fixed position with respect to the body. In a liquid, the particles are allowed to flow but are still fixed in place to a greater extent than a gas, where the particles are allowed to float randomly. This is an example of the statistical nature of entropy which calculates the probability that a given particle will be in a given place at a given time. This microscopic measure of entropy increases with an increasing number of possibilities of the position of the particle. The equation for the statistical measure of entropy is

$$S = k \log W$$

where S is entropy, k is a universal constant (Boltzmann's constant, $k = 1.38066 \times 10^{-23}$ (J/K)), and W corresponds to the number possibilities in which the parts of a system may be arranged. Entropy reaches a maximum when W reaches a maximum. For example, if there are 100 possible placements for the gas molecules, and W = 100, then the system has obtained the maximum amount of entropy possible. Since the system is in constant motion, no one arrangement is any more probable than any other.

Within the international political system, W would be analogous to the sheer number of countries, or sovereign nation-states, existing at a specified point in time. Figure 2 plots the number of countries within the international system, by decade, between 1800 - 1986 (according to Gurr's *Polity II* data). Figure 3 uses these same data to plot the amount of entropy within the international system between 1800-1980 due solely to the number of polities in the system.[1] Over the entire time period, we note the pronounced increase in both the number of countries within the international system (Figure 2), as well as the amount of entropy in the international system (Figure 3).

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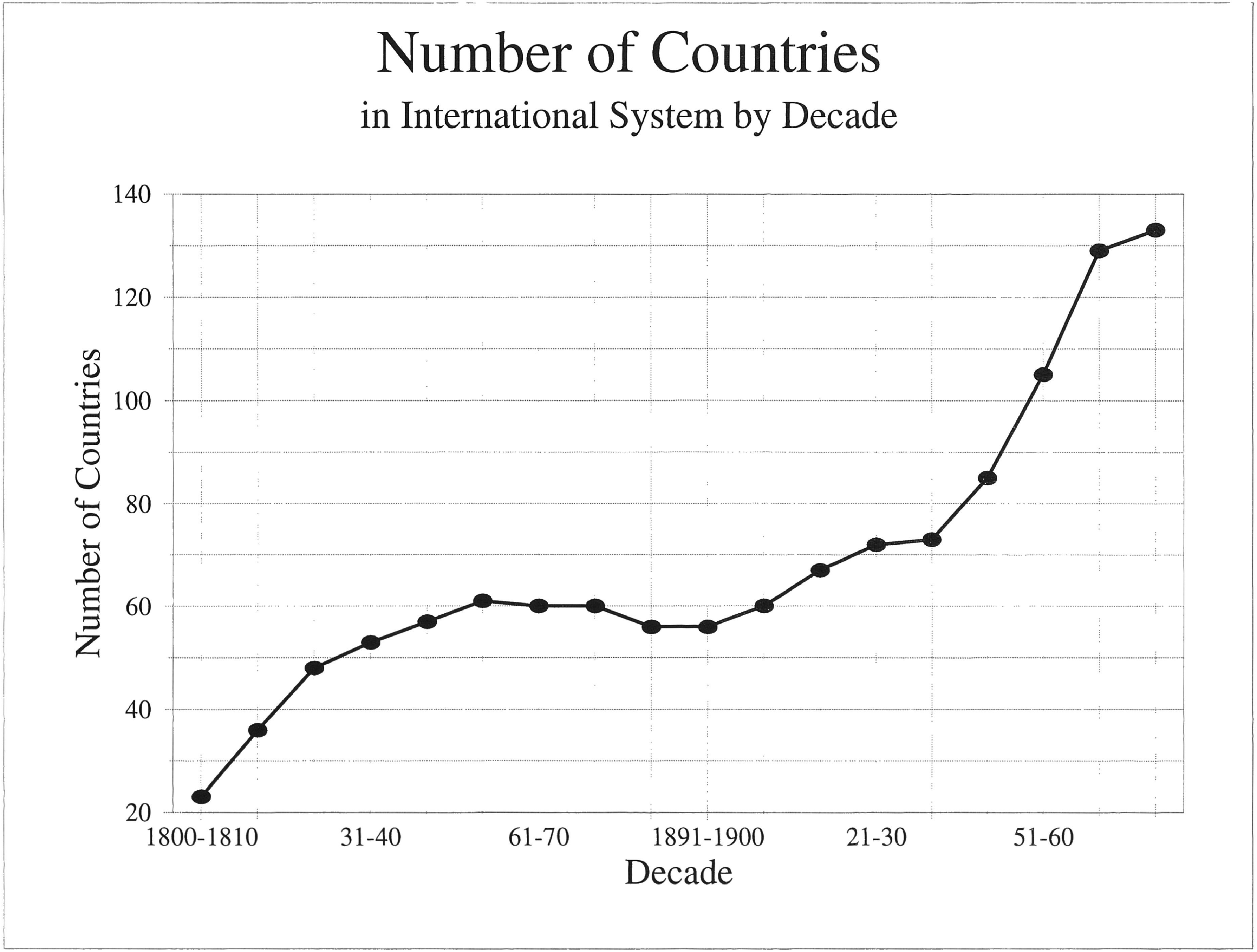
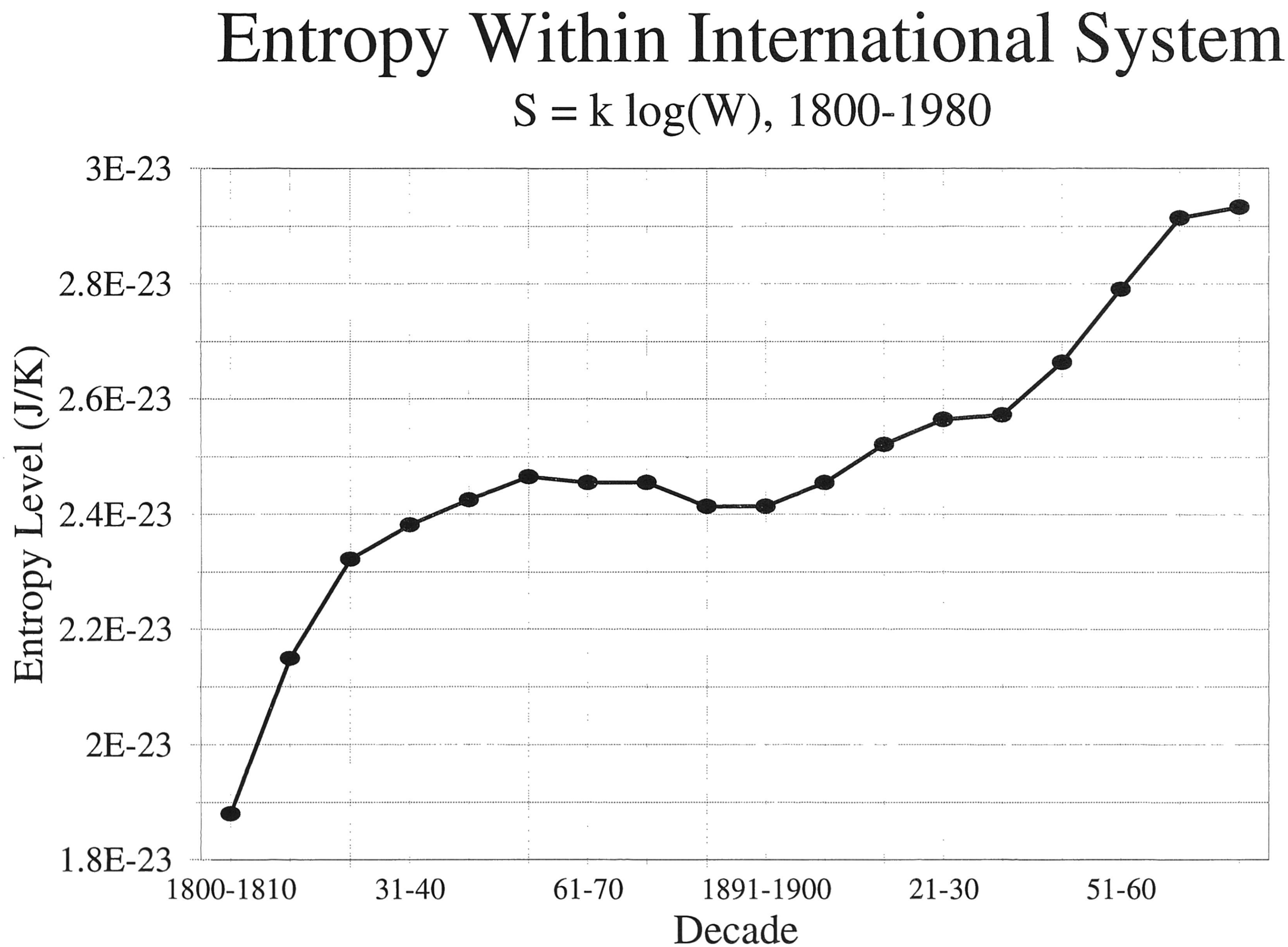
[1]Within the physical universe, entropy cannot decrease over time. Within the political world, however, we would expect the possibility that decreases in the number of nation-states could occur at various periods of history. This is clearly reflected in Figures 2 and 3, where the number of countries and entropy declines during the middle of the 19th century. This illustrates the very real limitations in extrapolating from physical properties to political and social properties; it does not, however, preclude the heuristic value of physical properties within political and social theories. Furthermore, over the entire time period (1800-1980), the trend is clearly in the direction we would expect (entropy increase).

Figure 2



Number of Countries
in International System by Decade
140
120
100
80
60
40
20
Number of Countries
1800-1810
31-40
61-70
1891-1900
21-30
51-60
Decade

Figure 3


Entropy Within International System
S = k log(W), 1800-1980
3E-23
2.8E-23
2.6E-23
2.4E-23
2.2E-23
2E-23
1.8E-23
Entropy Level (J/K)
1800-1810
31-40
61-70
1891-1900
21-30
51-60
Decade

Another characteristic of entropy is irreversibility. An irreversible process is one in which the system and all parts of its surroundings cannot be restored to their respective initial states after the process has occurred. Some of the things that would cause a physical process to be irreversible are: "heat transfer through a finite temperature difference, unrestrained expansion of a gas or liquid to a lower pressure, a spontaneous chemical reaction, a spontaneous mixing of matter at different compositions or states, friction (sliding friction as well as friction in the flow of fluids), electric current flow through a resistance, magnetization or polarization with hysteresis, and inelastic deformation." (Moran and Shapiro, p. 166). These portions of processes suggest that all physical processes are irreversible, since any physical process contains one or more of the above irreversibilities.

It is the same with political and social processes. "According to communication theory, there is no transmission of information without some loss of information." (Mueller, p. 95) Once an important piece of information has been received and processed, the perceptions and ideals of an individual can be forever changed. Even if a piece of information is received which counteracts or restores an initial viewpoint of the individual, any contacts the individual has influenced, or actions which have been taken, cannot be taken back without extra energy, work, and time being spent to restore the situation. Thus, information transactions are also irreversible processes.

Information transactions in the political system increase entropy within a system due to the nature of the human mind, the competitive nature of politics, and the technology that has brought constituent and representative closer together. The human mind will naturally put its own meaning to a piece of information due to its different environment and ambitions. If the same message were given to a group of ten random people, it is highly unlikely that the information would have the same interpretation or cause the same reaction in all ten people. If in fact this information is important and these ten people relay the message to ten more people, these messages are likely to cause even more diverse reactions among those affected. Entropy causes the information, which cannot be transferred without losses, to take on diverse meanings (Adams, p. 113). With an increased number of transactions, with or without knowing who has received what information, the probability of predicting the reactions of any individual becomes smaller and smaller. When this fact is coupled with the competitive nature of politics, it is easy to see that entropy increases.

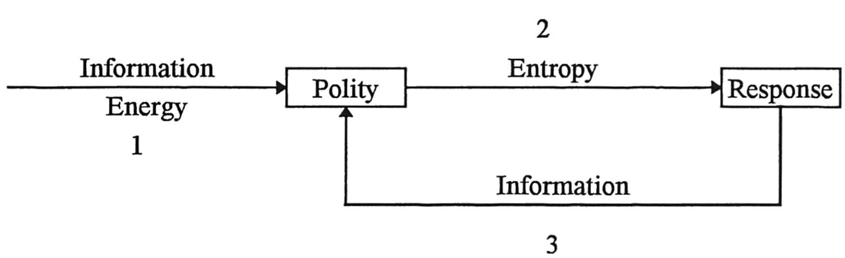
When an important bit of information causing affect is received by multiple parties, all having different interpretations and goals, the effect of their involvement with government will be the pressures of different forces acting on the government. With an increase in communications technology, and thus an increased ability to contact and apply pressure to the government, it is likely that the information will cause diverse reactions and thus increasingly opposite forces on government.

Political System Equilibrium and Stability

In classical thermodynamics, there is a strong emphasis on *equilibrium* states and the movement from state to state. A thermodynamic equilibrium refers to a balance of all forces and influences acting on and within the system. In a political system, changes in scope and energy (i. e., information) flux are among the principle causes for movement of a political system from equilibrium.

Stability and equilibrium are two similar but different concepts. Equilibrium is achieved when a balance of forces acting on a system is achieved. When a system is moved from equilibrium by a stimulus, it is considered stable if it gives the correct responses to remain stable. In testing the stability of a dynamic (characterized by constant motion) system, the three principle terms are *stimulus*, *response*, and *appropriate*. (Franklin, Powell, and Emami-Naeini, p. 212) The primary stimulus in the political system as seen in this paper is information. When new information is infused into a political system, it will cause entropy in the system. This stimulus demands an appropriate response by the system in order to remain stable. If the response is not appropriate, it will only serve to create more entropy in the system. This can be seen as the feedback loop shown in Figure 4.

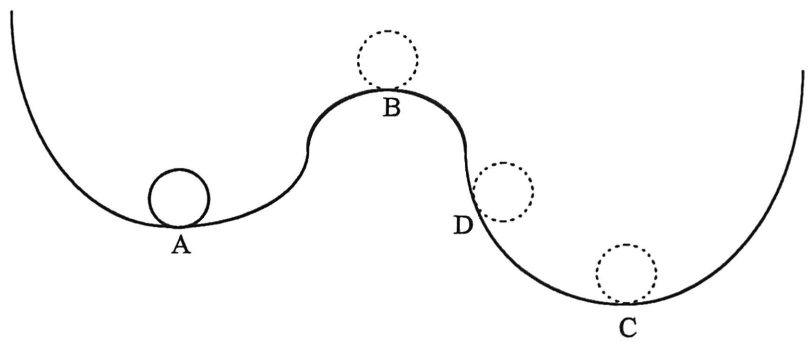
Figure 4 - Political system feedback loop.



As a political system or the international political system undergoes this loop, three important stages are seen. The first involves the information input into the political system. This information input, or flux, will lead to the second stage, which is the entropy production within the system. The third stage is the response of the political system which is produced in order to maintain stability. The result of this loop would be a cyclical movement from a dynamic equilibrium as entropy production increases and decreases with the responses of the political system to maintain stability. From this logic, large amounts of entropy will be manifested by large numbers of responses, or institutional changes.

Figure 5 gives a way to visualize the existence of multiple equilibrium states. (Gyftopoulos and Beretta, pp. 60-61) The system consists of a mass *m* which can move within a stationary bowl consisting of one peak and two valleys, all at different elevations. If the mass is stationary at any of the points a, b, or c, it will stay there under equilibrium by the balance of forces provided by gravity and the bowl, and these states will be defined as A, B, and C. Each of these states can be assigned an energy equal to the potential energy according to the their height in the gravity field. Although these states are all in equilibrium, A is metastable, B is unstable, and only C is stable. It is also seen that at state D, which is at an equal energy level of state A, equilibrium cannot be attained. Therefore, it is possible for two systems to have the same energy level without both being at equilibrium. (Gyftopoulos and Beretta, p. 61)

Figure 5 - Positions for classification of equilibrium and stability.



The stability of a political system may be thought of as a function of information, scope, institutional responses, and time. Due to the nature and adaptability of the human mind, if the information and scope within a system change substantially in a short amount of time, but thereafter remain constant, the humans within the system can adapt and reestablish stability. However, many would argue, including Thomas Jefferson, that change is good and that stability must be broken every so often to achieve a better environment and equilibrium in the future. It will also be seen that there are certain levels of information and scope which lead to equilibrium more quickly than other conditions. Obviously the most stable system is a static one, or one in which no one interacts or participates. In this case nothing would ever change. However, this system is the most susceptible to high levels of entropy production when one person or group decides to take action, without anyone to oppose them and help maintain a position near equilibrium by countering the forces and pressures enacted by the initial aggressor.

Scope, Diversity of Information Flow, and the Integrity of Structure

This paper does not attempt to give exact reasons for entropy production beyond information and scope flux, but rather which types of polities react faster to change, and which types of polities can handle entropy production in the most effective manner. In this paper, the analysis of political stability revolves around the relationship between scope and information. As stated earlier, the larger the scope, the greater the tendency for stability. With information flow, it is the large *diversity of information* which indicates an ability to maintain a position near a dynamic equilibrium. This is due to the large numbers of forces acting in different directions on society and government which are able to counteract and maintain each others positions and influence. This diversity makes it difficult for any one faction to have enough influence to quickly change the political environment. (Madison, p. 43)

Logically, we may posit four basic types of structural integrity characterizing nation-states at a defined point in time:

1). Low Scope/High Diversity of Information Flow

2). High Scope/High Diversity of Information Flow

3). Low Scope/Low Diversity of Information Flow

4). High Scope/Low Diversity of Information Flow

Following a thermodynamic logic, the political system with the lowest inherent entropy level would be one with high scope and low diversity of information flow. This is due to the high structure of the political system and the homogeneity of the information within. This situation is similar to the example given earlier of a solid as compared to a liquid or gas. Under this structure it becomes easier to predict the position, or movements of factions. The structure with the highest inherent level of entropy would be one with a low scope and high diversity of information flow. This is due to the minimal structure imposed on factions which have a diverse number of interests, and is similar to the gas in the same analogy. Factions within this structure could be moving in any direction, and are restricted minimally. However, this logic represents the current entropy levels within these types of polities and is not a prediction of the amount of entropy production which will occur within these polities.

Forming a hypothesis based on the Second Law of Thermodynamics, which states all systems move in a direction to minimize order, then the polities which would be expected to have the least to greatest entropy production are as ordered one to four above. The lowest levels of entropy production would occur in the subsystem that has high diversity of information flow and low scope, because it is very disorderly to begin with and nearest to stable equilibrium. The system which would be expected to have the highest entropy production over time is the most ordered because it has the furthest to go to reach stable equilibrium (although it may be at or reach metastable states). This hypothesis seems to be at odds with the explanation of current levels of entropy in the previous paragraph. However, if the assumption that this is a dynamic system is true, meaning that information flux is not constant and movements from equilibrium are unavoidable, then entropy will always propagate within the system.

The hypothesis also makes sense due to the nature of the four types of subsystems. With respect to the discussion on stability and equilibrium, we would expect those polities with a greater diversity of information flow to be more capable of reacting in such a manner as to maintain a position closer to equilibrium. Referring to the materials science analogy, it is expected that those polities with higher scopes are more effective in reducing the causes of entropy, but once critical levels of entropy are introduced into the system, it will shatter.

At this point it should be noted that polities with a highly diverse information flow cannot have as high of a scope as those polities with a low diversity of information. For example, due to the nature of the system, a totalitarian state, which has the highest obtainable scope, cannot be maintained under conditions of high diversity of information flow. Under a regime such as this, it may be the most difficult to impart change, but when change is initiated it would be expected for the regime to topple or change significantly. Using a microscopic thermodynamic logic, this system is the most homogeneous and organized of the four given possibilities. But due to its extreme rigidity, it cannot withstand any substantial changes without deforming the initial structure of the political system.

Operationalization

In order to test the hypotheses, the data set: *Political Structures and Regime Change, 1800-1986*, by Ted Gurr, was employed. The *Polity II* data set was designed to develop longitudinal indicators of political structures and regime change, and consists of annual codings of regimes structural characteristics, institutional changes, and the directionality of changes on underlying dimensions of democracy, autocracy, and power concentration." (Gurr, p. 1) These data were used with the SPSS statistical software package in order to sort through and cross reference certain variables within the *Polity II* data set. Each observation within the database represent a country-year. Therefore, the United States has 187 cases, or country-year observations in the dataset. If a country terminated during the 187 year period, or was created during the period, it will, of course, have fewer than the maximum 187 observations. The total number of country-year observations in the dataset is 12,459. For clarity of presentation, we have aggregated the data by decade between 1800-1986.

The values of scope used in the evaluation are the original values from the *Polity II* data set and did not require recoding except for separating them into high scope and low scope categories. In the data set scope is coded from 1 - 9, high to low scope, respectively.

In order to obtain a measure for the diversity of information flow within a political system, several variables from *Polity II* were combined into an index, with equal weights assigned to each variables within the index. The original individual variables, original values, and recoded values are summarized in Table 1. When the individual values of each variables in the index were added together, the resulting index assumed values ranging from 7 - 21, with low being the minimal value for diversity of information, and 21 the maximum value of diversity of information flow. This index was set to a standard scale, with 0 being equal to the minimal value, and 14 the maximum value. All missing data were excluded from the analysis.

Table 1 - Variable index of diversity of information flow.

Variable	Originally Coded Values	Recoded Values
Regulation of Executive Recruitment	1-3, low to high	3 = 1; 2 = 2; 1 = 3
Competitiveness of Executive Recruitment	1-3, low to high	remained the same
Openness of Executive Recruitment	1-4, closed to open	1,2 = 1; 3= 2; 4 = 3
Executive Constraints	1-7, minimal to maximum	1,2 = 1; 3,4,5 = 2; 6,7 = 3
Regulation of Political Participation	1-5, low to high	1,2 = 3; 3 = 2; 4,5 = 1
Competitiveness of Political Participation	1-5, low to high	1,2 = 1; 3 = 2; 4,5 = 3
Centralization of Political Authority	1-3, high to low	remained the same

Finally, scope and diversity of information flow have been combined to derive empirical measures of the four logical types of structural integrity, discussed earlier. Table 2 below describes the four types of structural integrity that characterize the sample of country-year observations between 1800-1986.

Table 2 - Expectations and examples for the structures of integrity.

SCOPE \ DIVERSITY	Low	High
High	*Prediction*: High entropy production *Description*: Strong, but brittle structure; low resilience to information flux *Examples* (1970 - 1986): Bulgaria, China, Iraq, Jordan, Morocco, USSR *Percent Valid Observations* (1800-1986): 45.6%	*Prediction*: Low to moderate entropy production *Description*: Strong, but brittle structure; high resilience to information flux *Examples* (1970 - 1986): Denmark, France, Israel, New Zealand, Nigeria, USA *Percent Valid Observations* (1800-1986): 13.2%
Low	*Prediction*: Moderate to high entropy production *Description*: Weak ductile structure; low resilience to information flux *Examples* (1970 - 1986): Guatemala, Lebanon, Pakistan, Switzerland *Percent Valid Observations* (1800-1986): 10.5%	*Prediction*: Low entropy production *Description*: Weak ductile structure; high resilience to information flux *Examples* (1970 - 1986): Cameroon, Indonesia, Nicaragua, Uganda *Percent Valid Observations* (1800-1986): 30.7%

Entropy is operationalized as the number of institutional changes within a political system over a defined space of time. The critical institutional authority patterns are similar to those included within our measure of diversity of information flow. However, the two variables are logically independent of each other: the diversity of information flow records the nominal *level* of a country's authority pattern within a given year, while entropy measures the volume of *change* of authority patterns within a given year. Consistent with the logic of thermodynamic principles, we argue that the nature of authority patterns (along with the scope of authority) manages information flux within a political system. This information flux should be better absorbed by the institutional structure of a political system when the level of authority pattern in the political system is closer to democratic patterns of political authority. Or, stated slightly differently, entropy is a function of scope and diversity of information flow, as reflected by the four logical types of structural integrity.

Therefore, we may state the principal hypothesis of this study as:

> *entropy within a political system varies as a function of the structural integrity of a political system.*

Table 3 - Review of principle operationalizations

Thermodynamic Concepts	**Political Analogy**	**Operationalization**
Energy Potential energy Kinetic energy Internal energy	Information Unknown information Known information Microscopic properties	Diversity of information flow
Structure	Scope	Scope
Entropy	Institutional change	Institutional change

Results

Four figures and four tables are presented in this section in order to give a graphical representation of the data used in testing the hypotheses. It is important to note which graphs give a *total* or *mean* value for entropy measurements. Those graphs which show *total entropy values* are the average levels of entropy produced cumulatively from the initial year through any given point on the graph. Total entropy is simply the sum of the entropy production for each decade. Those graphs which give *mean values represent the average entropy production* within the last decade. This is important to note due to the implications of the Second Law of Thermodynamics. *Entropy production can decrease from decade to decade, but as long as the entropy production is not negative (which is impossible by the Second Law of Thermodynamics) the total entropy in the system always increases.*

Figure 6 plots the mean value of scope for all countries in the international system for 1800 - 1986. The scale of Scope in the *Polity II* data set was reversed so that increasing values would also represent an increase in scope graphically. Figure 7 plots the mean diversity of information flow for the international system for 1800 - 1986. Figure 8 plots the mean entropy (Institutional Change) production in the international system by decade from 1800 - 1986, for each scope and diversity of information flow subsystem.

Table 4 gives mean values and confidence intervals associated with the measurement of entropy in the international system from 1800 - 1986. Table 5 gives the analysis of variance for the groups used to obtain Table 4. Table 6 gives mean values and confidence intervals associated with the measurement of entropy in the international system from 1921 - 1986. Table 7 gives the analysis of variance for the groups used to obtain Table 6. Tables 6 and 7 resulted from a second test which was done in light of the fact that high scope values did not occur in the international system until the early twentieth century. This allowed for all four thermodynamically logical systems to interact in the international system. However, this also heavily decreases the time span for the test and opens the door to possible anomalies in the data which could skew the means for such a relatively short period of time.

Other relevant figures are provided in Appendix A. Figure 9 plots the mean entropy production in the international system by decade from 1800 - 1986. Figure 10 plots the total entropy production within the international system from 1800 - 1986. Figure 11 plots the number of cases in the international system for each type of the four systems by decade from 1800 - 1986. It should be noted that if a country exists for one decade, there are ten cases, one for each year of existence. Figure 12 plots the total entropy production for each of the four systems from 1800 - 1986. Figure 13 plots the total entropy production for each of the four systems from 1921 - 1986.

Figure 6

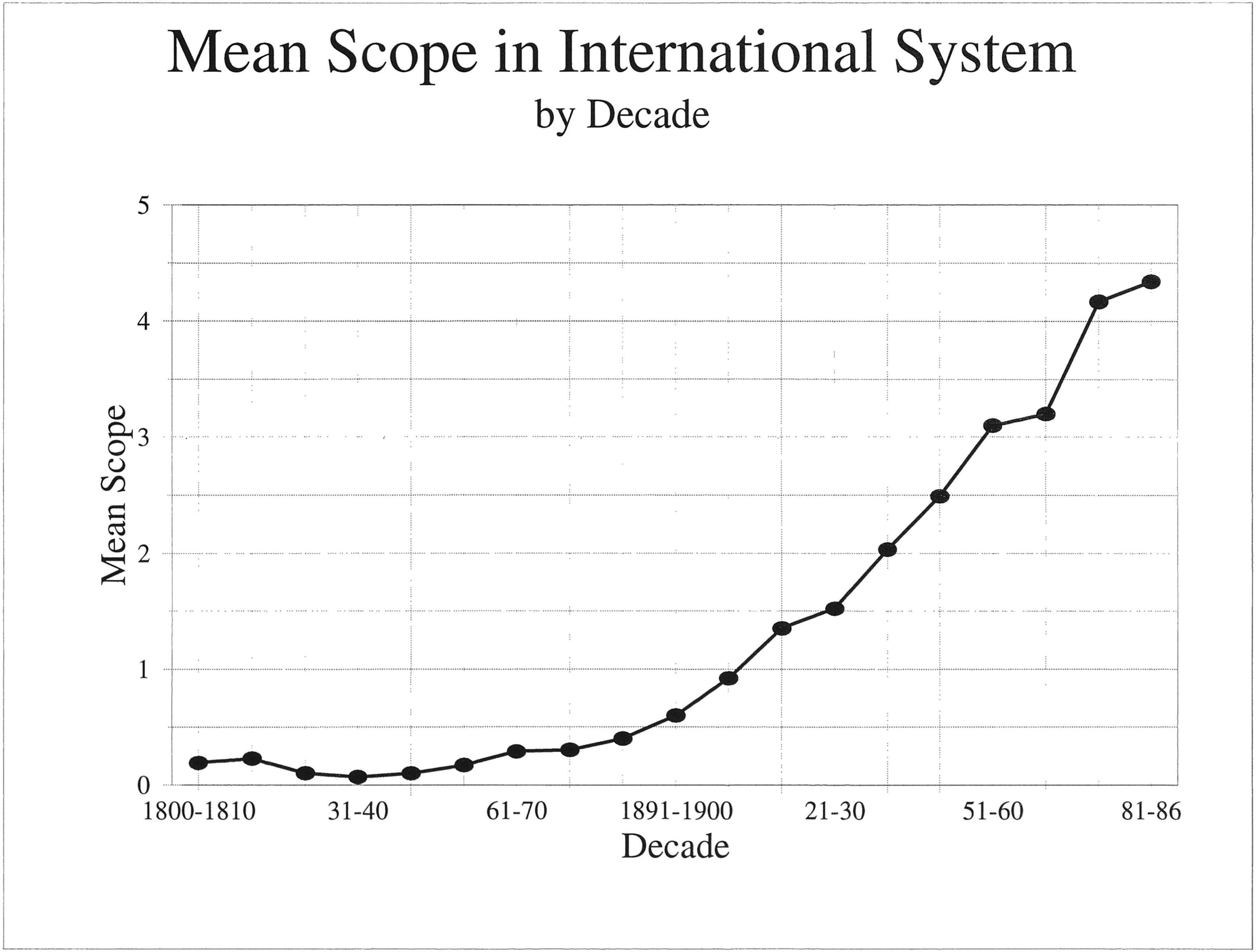
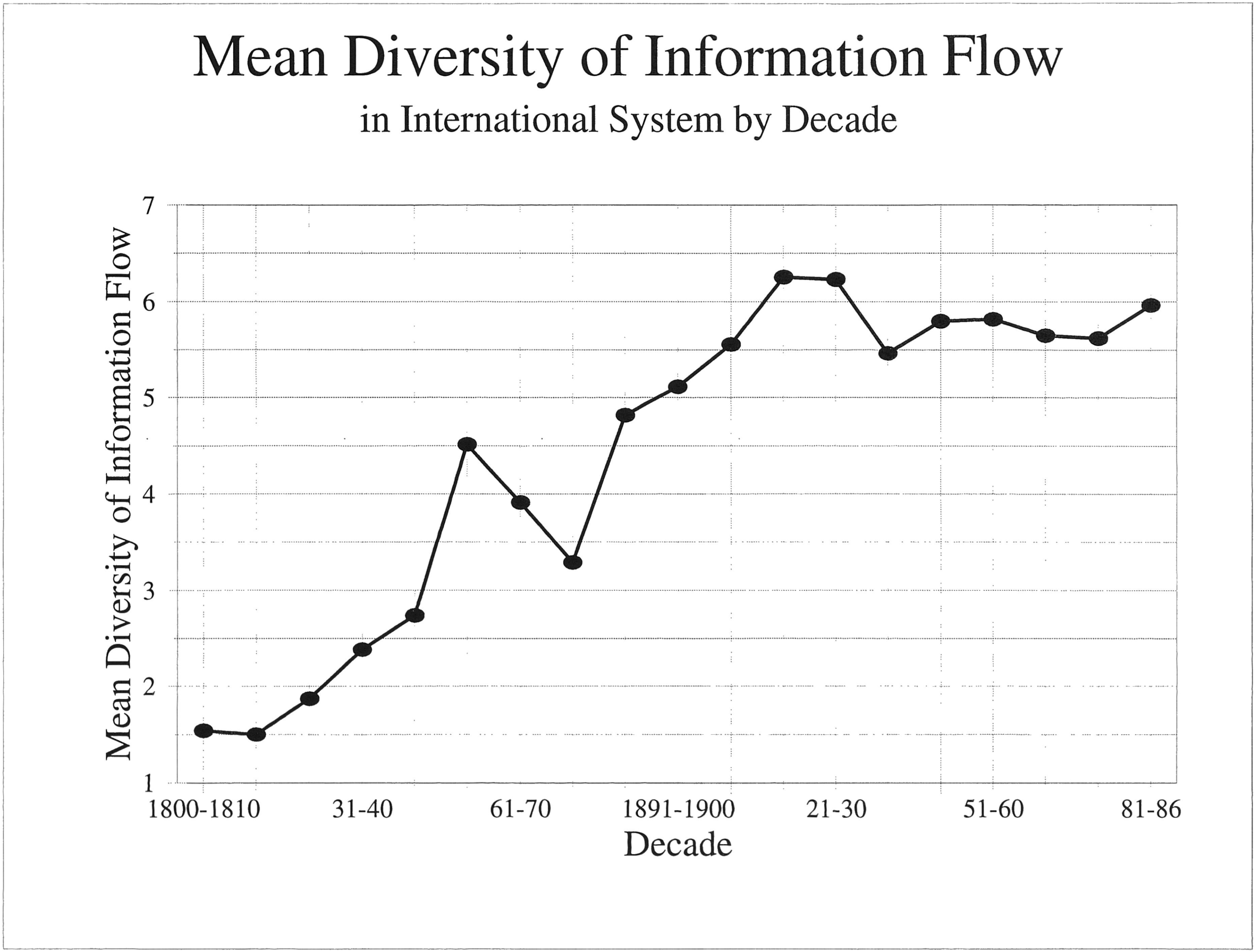

Mean Scope in International System
by Decade
Mean Scope
0
1
2
3
4
5
1800-1810
31-40
61-70
1891-1900
21-30
51-60
81-86
Decade

Figure 7



Mean Diversity of Information Flow
in International System by Decade
Mean Diversity of Information Flow
7
6
5
4
3
2
1
1800-1810
31-40
61-70
1891-1900
21-30
51-60
81-86
Decade

Figure 8

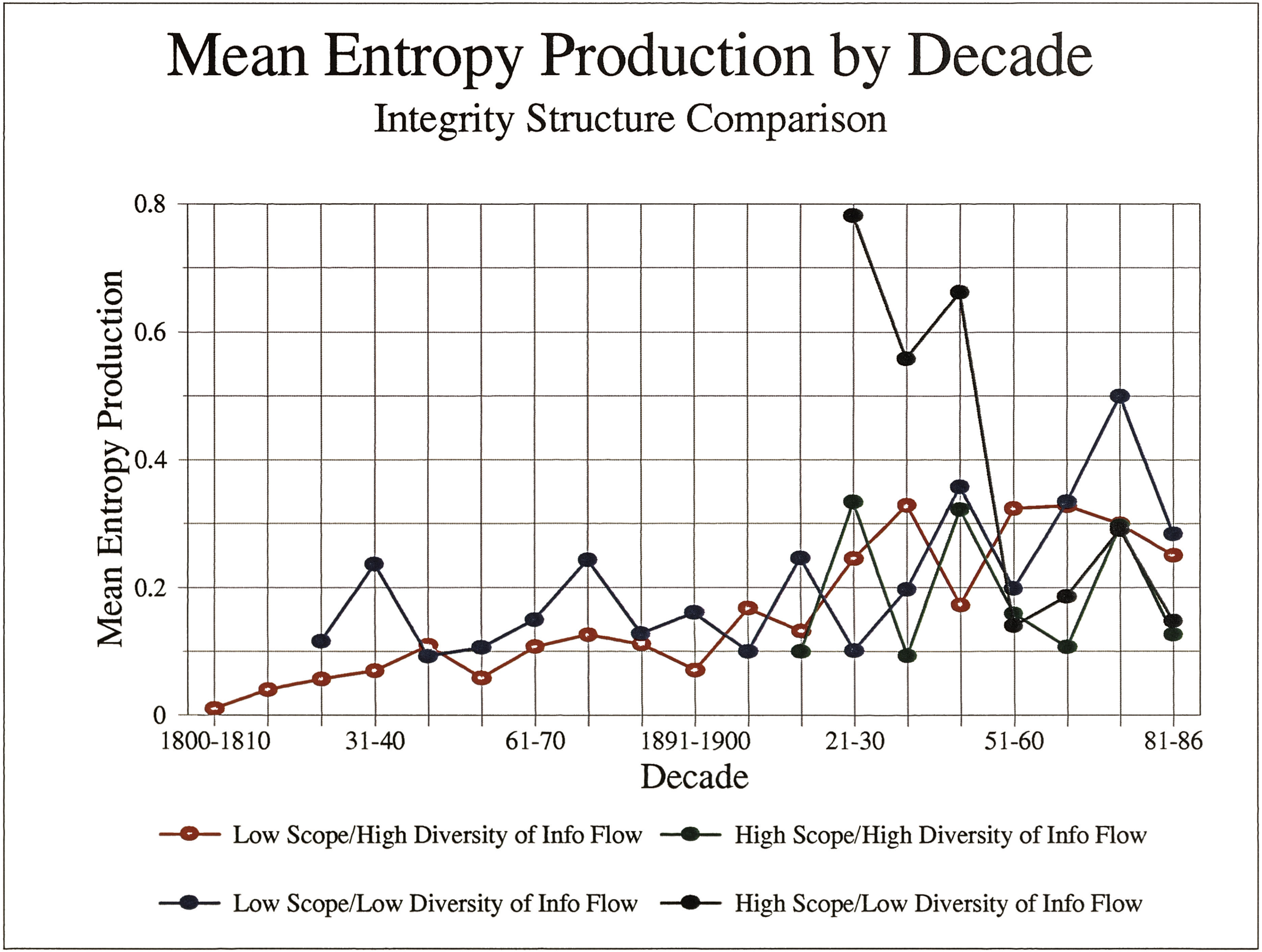

Mean Entropy Production by Decade
Integrity Structure Comparison
Mean Entropy Production
0.8
0.6
0.4
0.2
0
1800-1810
31-40
61-70
1891-1900
21-30
51-60
81-86
Decade
Low Scope/High Diversity of Info Flow
High Scope/High Diversity of Info Flow
Low Scope/Low Diversity of Info Flow
High Scope/Low Diversity of Info Flow

Table 4 - Entropy in international system (1800 - 1986).

Polity Category	Mean Value	95% Confidence Interval
Low Scope and High Diversity of Information Flow	0.1432	(0.1228, 0.1636)
High Scope and High Diversity of Information Flow	0.1936	(0.1515, 0.2357)
Low Scope and Low Diversity of Information Flow	0.2072	(0.1770, 0.2373)
High Scope and Low Diversity of Information Flow	0.2818	(0.2237, 0.3399)

Table 5 - Analysis of variance of entropy in international system (1800 - 1986).

Polity Category	Sum of Squares	DF	Mean Square	F
Between Groups	18.900	3	6.300	10.346**
Within Groups	5927.334	9734	0.610	
Totals	5946.234	9737		

* 0.01 > p > 0.05

** p < 0.01

Table 6 - Entropy in international system (1921 - 1986).

Polity Category	Mean Value	95% Confidence Interval
Low Scope and High Diversity of Information Flow	0.2902	(0.2354, 0.3450)
High Scope and High Diversity of Information Flow	0.1951	(0.1524, 0.2378)
Low Scope and Low Diversity of Information Flow	0.2512	(0.2038, 0.2985)
High Scope and Low Diversity of Information Flow	0.2839	(0.2252, 0.3426)

Table 7 - Analysis of variance of entropy in international system (1921 - 1986).

Polity Category	Sum of Squares	DF	Mean Square	F
Between Groups	6.919	3	2.306	2.753*
Within Groups	4213.088	5029	0.838	
Totals	4220.007	5032		

* 0.01 > p > 0.05
** p < 0.01

Analysis

As seen in Figure 6, mean scope in the international system increases with time. Scope does not start to increase rapidly until the end of the nineteenth century. The lack of scope until this time is due to the lack of technology which is required for government to impart scope on its citizens. It would be expected in the future that scope within the international system will reach a maximum and flatten out if the international system is going to maintain a moderate diversity of information flow.

The mean diversity of information flow (Figure 7) increases from 1800 to approximately 1910, at which time it levels off. This is due to the increasing scope in the system. As mentioned previously, scope limits diversity of information flow, and visa versa.

Figure 8 shows the behavior of the different structure types from 1800 - 1986. The cyclic fluctuations which would be expected from the polity feedback loop are shown quite distinctly. As expected, high scope polities have larger fluctuations, due to their rigidity, than do low scope polities which are more ductile. The cycles for the high scope and low diversity of information flow structure are the most extreme. In the decades from 1921 - 1950, a large entropy production is observed. The entropy production then drops to a low value as the system regroups. This is also a manifestation of its weak ability to react in a quick manner due to its low diversity of information flow. As expected, this system had a relatively large reaction time (three decades) to return to low levels of entropy production. The low scope, high diversity of information flow structure maintains a much steadier level of entropy production. This is due to its ductile structure and strong ability to react quickly with its high level of diverse information flow. In general, it is seen that with respect to their equivalent scope levels, high levels of diverse information flow have lower levels of entropy production as well as smaller fluctuations than do structures with low diversity of information flow. It is also seen that a general progression toward larger entropy production occurs. This is attributed to the growing number of countries within the international political system (Figure 2).

In conjunction with Figure 8, Tables 4 and 6 show the mean entropy production values for the different types of structural integrity for the years of 1800 -1986, and 1921 - 1986, respectively. In Table 4, the results give values which were expected by logic presented in this paper. Table 6 shows a similar trend with the exception of the low scope and high diversity of flow structure. This structure actually has the highest level of entropy production for this time period, when it was expected to have the lowest production. This could possibly be explained by the short time period used for this evaluation, which allows for a decade of prevalent entropy to have a large effect upon the mean for the six decades recorded in Table 6. Upon further inspection, the decade of 1961 - 1970 is observed to have a relatively high level of entropy production, which also coincides with the most cases present within this structure from 1921 - 1986. This can be explained in part as a result of the historically unique circumstance of extensive de-colonization which began in earnest after 1955. This resulted in a large number of new countries forming out of colonial empires, collectively possessing lower levels of scope yet characterized in many instances by high diversity of information flows. The "newness" of this set of countries left their scope levels lower and less established, and, in conjunction with institutionally manifested diverse information flows, made these new nation-states susceptible to periods (sometimes protracted) of instability and transformation.

Tables 5 and 7 show an analysis of variance for the measure of entropy within the international system for the years 1800 - 1986, and 1921 - 1986, respectively. This analysis shows that the integrity structures tested differed enough such that the values of entropy obtained are statistically significant.

Figure 9 (Appendix A) shows the increasing mean entropy production increasing with time in the international system. This is possibly attributable to the growing number of countries in the international system. In fact, it can be seen that the lull in entropy production in the international system from 1881 - 1910, directly correlates with the slight decrease in number of countries in the international system (Figure 2) at that time.

Further studies which would prove beneficial towards the evolution of the general thermodynamic principles in this paper could include an analysis of critical time periods on the different political structures. These would include such events as war and depression. The effects of war and depression on the scope and information flow of individual countries within the international system should be examined in more detail. Other possibilities could include an analysis of the effects of scope and information flow on the coherence of government institutions within a an individual polity and the international system. Other, more detailed sources of information could also be used for a closer analysis of the trends of stability within a specific country or government institution. These future analyses should include quasi-experimental techniques (e.g., interrupted time-series).

Conclusions

This paper has demonstrated the logical, heuristic relationship between thermodynamic principles and the structural logic of the international political system. Political scientists have long used systemic interpretations of power and authority to explain the actions of groups and nations. These interpretations, however, have too often lacked explicit specification of the principles which justified the very logic of systems analysis in the first place. The result has been a gradual erosion of systems analysis as a major paradigm within the field of political science. Increasingly, political scientists have turned to the paradigm of rational choice as the preferred framework within which to explain political behavior. This, however, has resulted in a growing uneasiness with what some fear may be a too reductionist interpretation of political behavior. The sole interpretation for political behavior is seen often as merely the individual incentives and motivations of the rational actor. What is missing in this paradigm is a broader perspective within which to adjust and evaluate the range of choice available to individual actors. Systemic pressures, if not fully understood, impose significant constraints not only on the actions of the individual actors, but prevent the very information that shape the priorities and motivations of the actors. Thus, what is rational may well be spurious: it is rational because the systemic pressures in the international (or domestic) environment have imposed, *by its own logic*, severe boundaries on the options open of the individual (whether that individual is a human, or is a coordinated collective, such as a nation-state).

The very real limitations of a rational actor model for political behavior is seen across the globe each day. What from one perspective may be seen as merely the result of rational actors pursuing their interests, may also be seen as the desperate reactions of people or nations responding to increasing pressure form outside their boundaries. Their responses, interpreted within a rational actor framework, may ease the complexity of interpretations, but they may also miss the most important point: the behavior is neither rational or irrational—but simply arational. It is a function of systemic pressures defined by the very structure within which they live. Can one really say that the Soviet union collapsed (despite the predictions of Sovietologists to the contrary) merely because communism was corrupt? Or, because the American weapons systems had reached a level of technical sophistication that could not be matched by inferior Soviet technology? Perhaps our appreciation and understanding of this crucial twentieth century event might be extended if it is viewed as a result of growing systemic pressures caused by the severe restrictions of information flow as a function of both formal censorship and lack of sophisticated communication technology. This lack of information simply prevented the uniform forces required to maintain equilibrium within a dynamic system. Between 1917 and 1990, the USSR had been able to withstand a build up of entropy as a result of the significant scope within its political system. Yet, the brittleness of this scope finally caused the Soviet political system to rapidly fracture, leaving a fragmented empire and a disjointed economy in its wake.

While similar examples can be easily found across the contemporary global landscape, it seems sufficient at this juncture to merely remind ourselves that while rational behavior may certainly influence political behavior and the interaction of nation-states, systemic pressures serve to force actors to select options from dynamic sets which change with information flux. Abraham

Lincoln understood this all too well when he admitted near the end of the American Civil War that "I claim not to have controlled events, but confess that events have controlled me."

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Appendix A - Relevant Figures

Figure 9

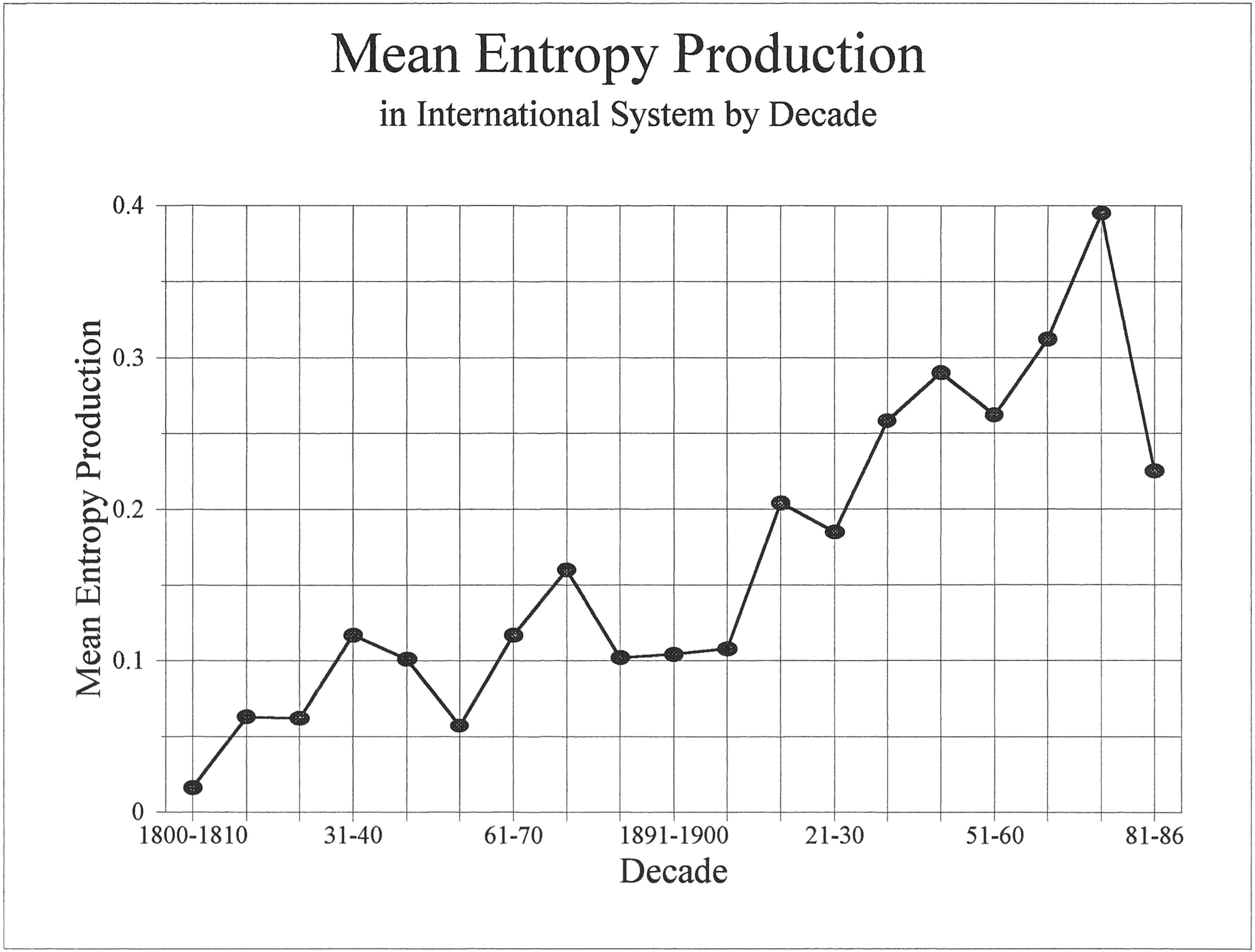

Mean Entropy Production
in International System by Decade
Mean Entropy Production
0.4
0.3
0.2
0.1
0
1800-1810
31-40
61-70
1891-1900
21-30
51-60
81-86
Decade

Figure 10

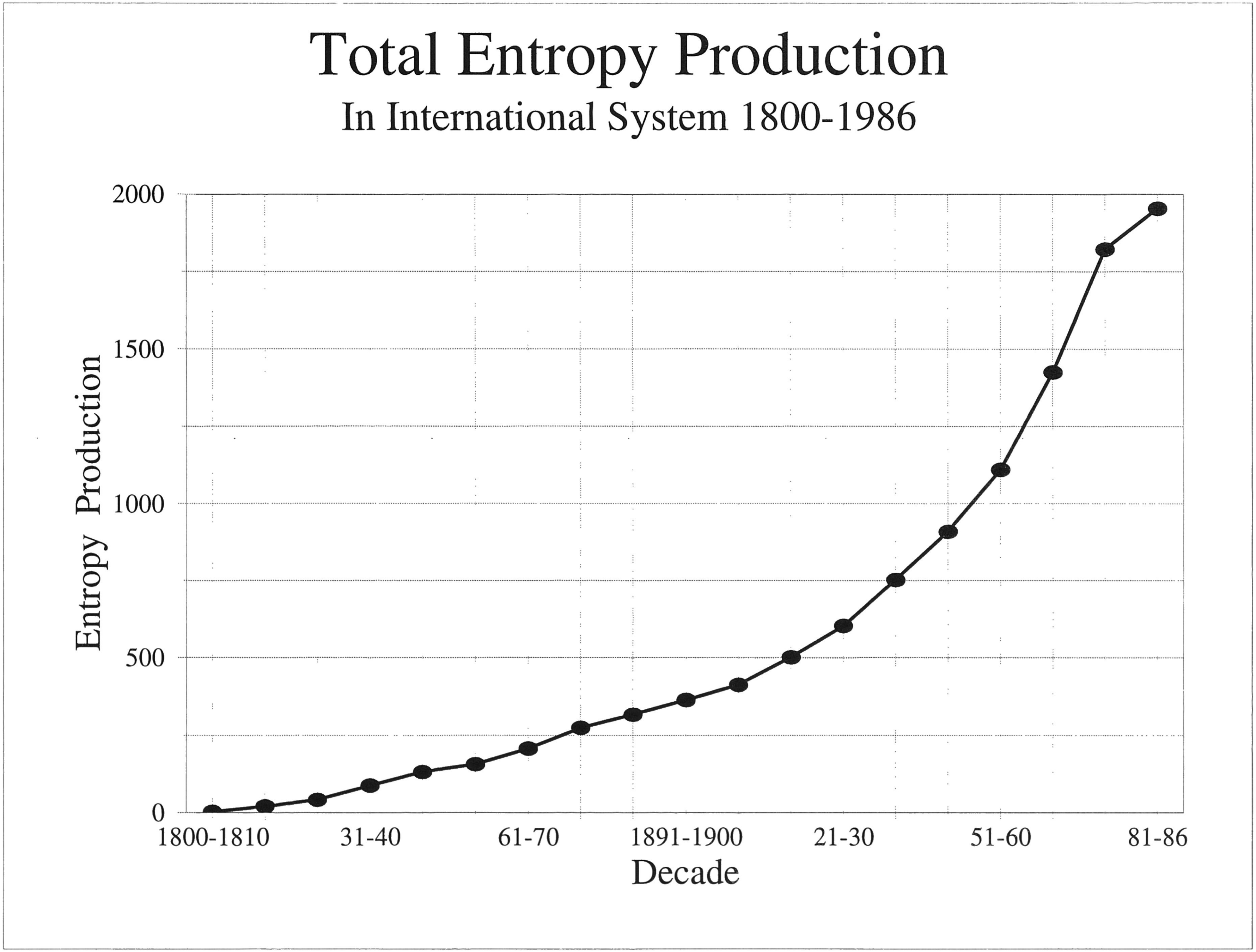

Total Entropy Production
In International System 1800-1986
Entropy Production
2000
1500
1000
500
0
1800-1810
31-40
61-70
1891-1900
21-30
51-60
81-86
Decade

Figure 11

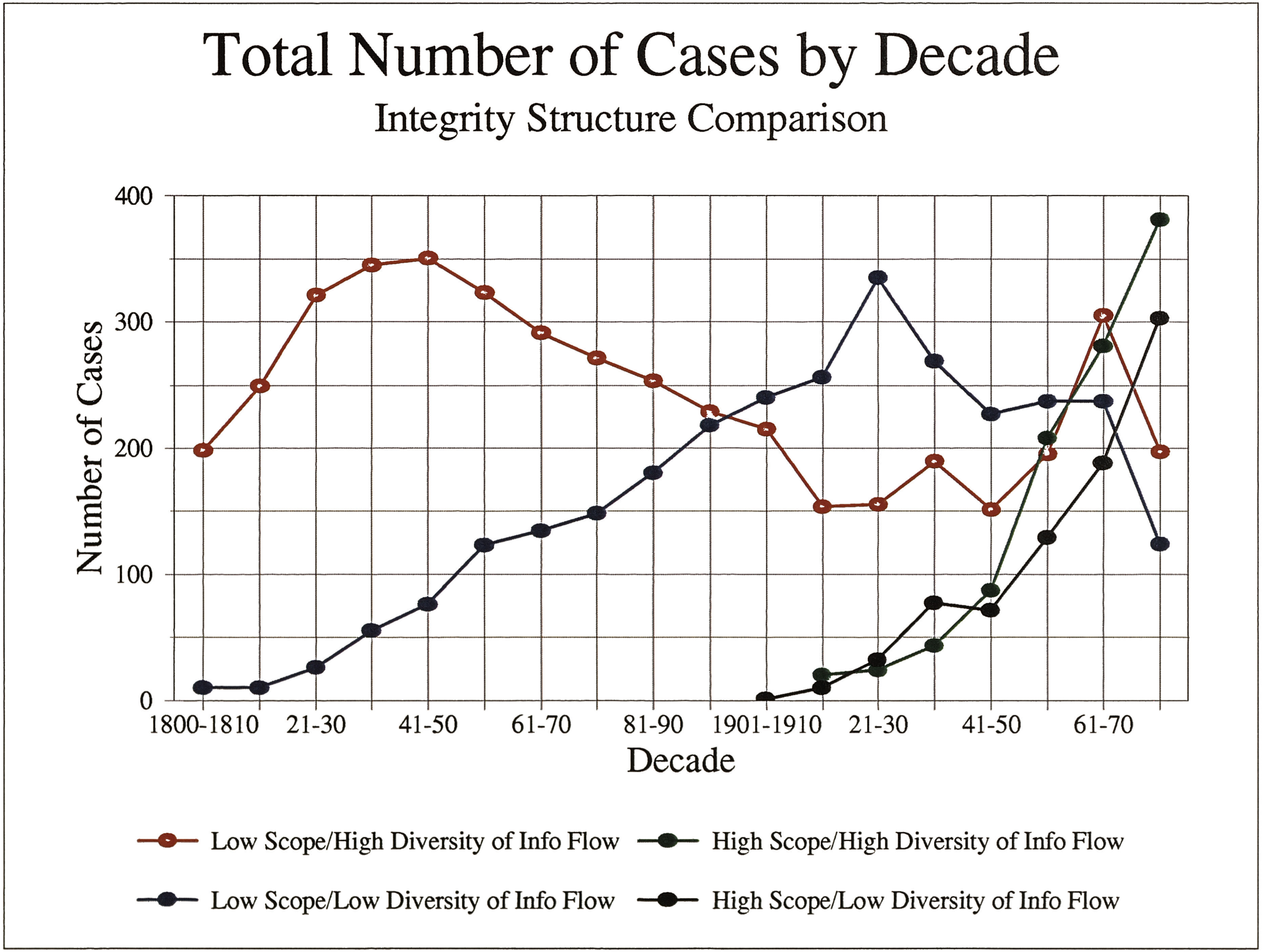
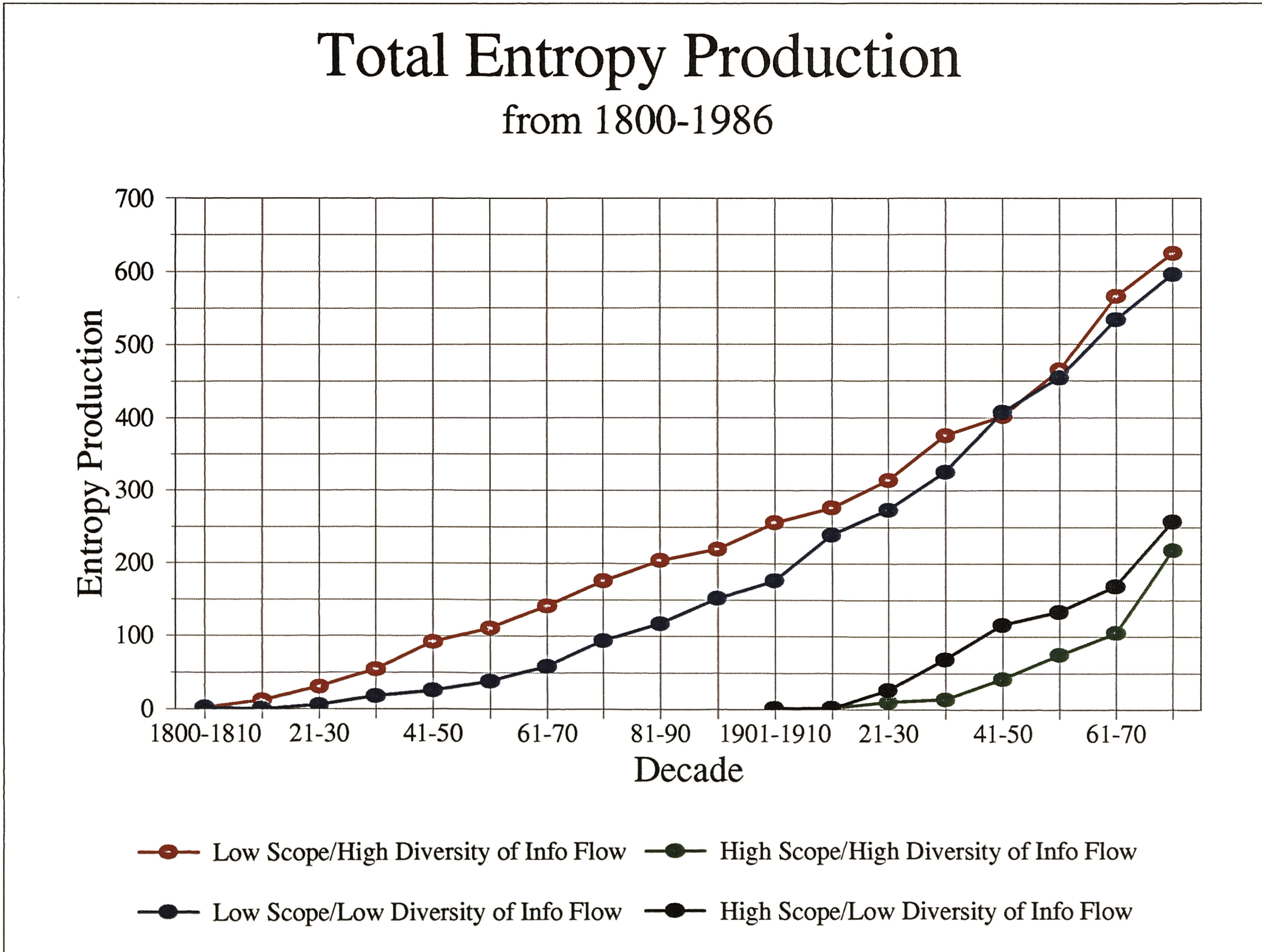
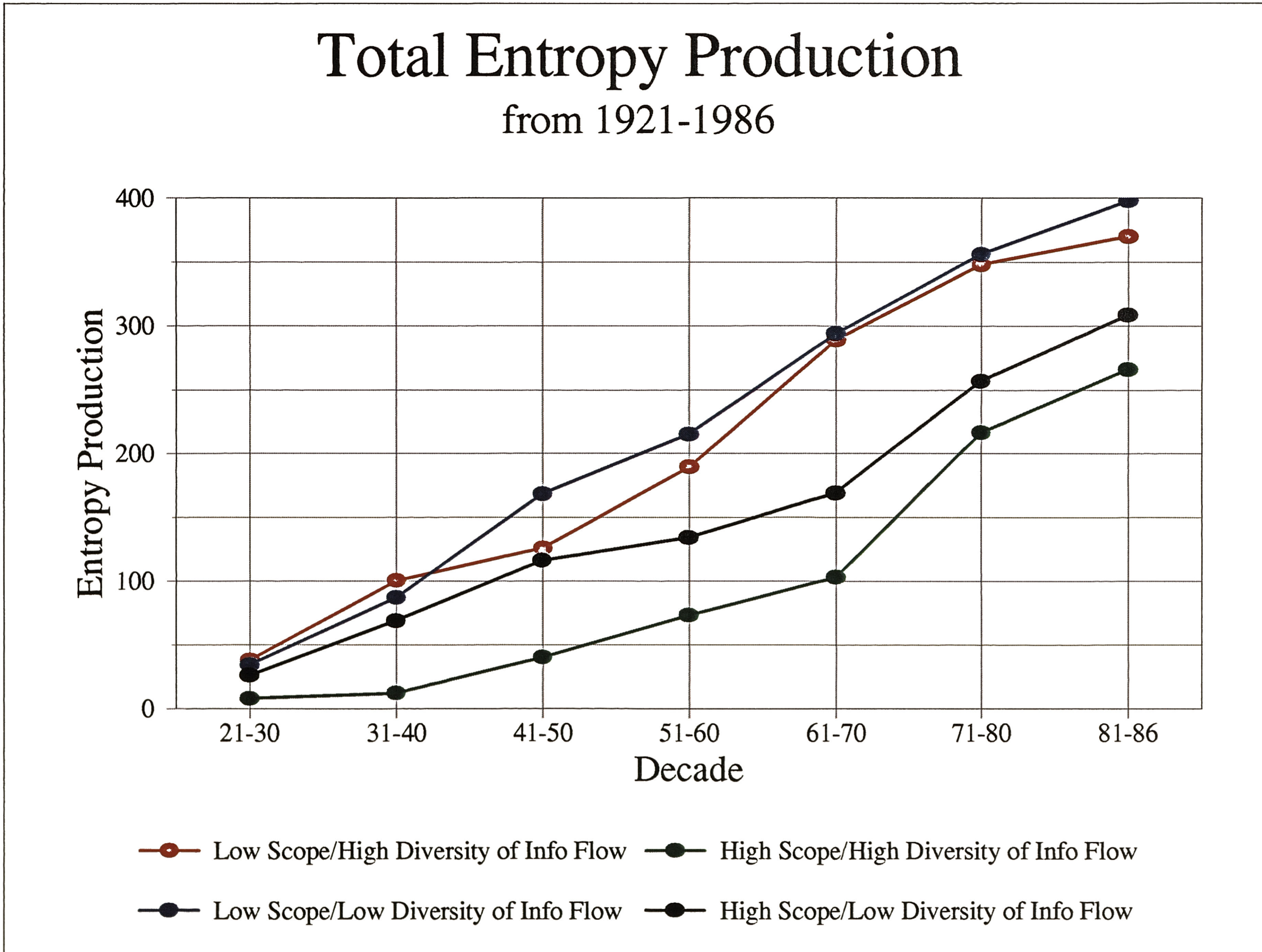

Total Number of Cases by Decade
Integrity Structure Comparison
Number of Cases
400
300
200
100
0
1800-1810
21-30
41-50
61-70
81-90
1901-1910
21-30
41-50
61-70
Decade
Low Scope/High Diversity of Info Flow
High Scope/High Diversity of Info Flow
Low Scope/Low Diversity of Info Flow
High Scope/Low Diversity of Info Flow

Figure 12



Total Entropy Production
from 1800-1986
Entropy Production
700
600
500
400
300
200
100
0
1800-1810
21-30
41-50
61-70
81-90
1901-1910
21-30
41-50
61-70
Decade
Low Scope/High Diversity of Info Flow
High Scope/High Diversity of Info Flow
Low Scope/Low Diversity of Info Flow
High Scope/Low Diversity of Info Flow

Figure 13


Total Entropy Production
from 1921-1986
Entropy Production
400
300
200
100
0
21-30
31-40
41-50
51-60
61-70
71-80
81-86
Decade
Low Scope/High Diversity of Info Flow
High Scope/High Diversity of Info Flow
Low Scope/Low Diversity of Info Flow
High Scope/Low Diversity of Info Flow

Appendix B - Scope and Diversity of Information Flow for Polities (1800-1986)

Country (Country Code)	Low Scope/ High Div (Info)	High Scope/ High Div (Info)	Low Scope/ Low Div (Info)	High Scope/ Low Div (info)
Afghanistan 700	X			
Albania 339				X
Algeria 615				X
Angola 540		X		X
Argentina 160		X		X
Australia 900		X	X	
Austria 305		X		
Bangladesh 771	X		X	
Belgium 211		X		
Benin 434			X	
Bhutan 760		Missing Data		
Bolivia 145		X		
Botswana 571		X		
Brazil 140	X		X	
Bulgaria 355				X
Burkina Faso 439		Missing Data		
Burma 775		Missing Data		
Burundi 516		Missing Data		
Cameroon 471	X			
Canada 020		X	X	
Central African Rep. 482	X			
Chad 483	X			
Chile 155		X		
China (PRC) 710				X
Colombia 100		X	X	
Congo 484	X			X
Costa Rica 94		X		
Cuba 40		Missing Data		
Cyprus 352		X	X	
Czechoslavakia 315				X
Denmark 390		X		
Dominican Republic 42			X	
Ecuador 130		X	X	
Egypt 651		X		X
El Salvador 92	X		X	
Ethiopa 530		Missing Data		
Finland 375		X		
France 220		X		
Gabon 481	X			
German Dem. Rep. 265				X
German Fed.Rep. 260		X		
Ghana 452	X	X		
Greece 350		X		
Guatemala 90			X	
Guinea-Bissau 404		Missing Data		
Guinea 438				X
Guyana 110		X		X
Haiti 41	X			
Honduras 91			X	

Country (Country Code)	Low Scope/ High Div (Info)	High Scope/ High Div (Info)	Low Scope/ Low Div (Info)	High Scope/ Low Div (info)
Hungary 310				X
Iceland 395		X		X
India 750		X	X	
Indonesia 850	X			
Iran 630				X
Iraq 645				X
Ireland 205		X		
Israel 666		X		
Italy 325		X		
Ivory Coast 437	X			X
Jamaica 51		X		
Japan 740		X	X	
Jordan 663				X
Kampuchea 811		Missing Data		
Kenya 501	X			X
Korea, Dem. People Rep. 731				X
Korea, Republic of 732		X		X
Kuwait 690				X
Laos 812	X			
Lebanon 660			X	
Lesotho 570	X	X	X	
Liberia 450	X			
Libya 620		Missing Data		
Lithuania 368		Missing Data		
Luxembourg 212		X		
Madagascar 580	X	X		
Malawi 553	X			
Malaysia 820		X	X	
Mali 432		Missing Data		
Mauritania 435	X			X
Mauritius 590		X	X	
Mexico 70		X		
Mongolia 712				X
Morocco 600				X
Mozambique 541				X
Nepal 790	X			
Netherlands 210		X		
New Zealand 920		X		
Nicaragua 93	X			
Niger 436	X			
Nigeria 475		X		
Norway 385		X		
Oman 698		Missing Data		
Pakiston 770			X	
Panama 95		Missing Data		
Papua New Guinea 910		X		
Paraguay 150	X			
Peru 135		X	X	
Philippines 840	X		X	

Country (Country Code)	Low Scope/ High Div (Info)	High Scope/ High Div (Info)	Low Scope/ Low Div (Info)	High Scope/ Low Div (info)
Poland 290				X
Portugal 235	X	X	X	
Rumania 360				X
Rwanda 517	X			
Saudi Arabia 670	X			X
Senegal 433	X		X	
Sierra Leone 451	X		X	X
Singapore 830		X	X	
Somalia 520		Missing Data		
South Africa 560		X		
Spain 230			X	
Sri Lanka 780		X	X	
Sudan 625				X
Sweden 380		X		
Switzerland 225			X	
Syria 652				X
Taiwan 713	X			X
Tanzania 510				X
Thailand 800	X		X	
Togo 461		Missing Data		
Trinidad & Tobago 52		X		
Tunisia 616	X	X	X	X
Turkey 640		X	X	X
U.S.A. 2		X		
U.S.S.R. 365				X
Uganda 500	X			
United Kingdom 200		X		
Uruguay 165	X	X	X	X
Venezuela 101		X	X	
Vietnam, Dem. Rep. of 816				X
Vitman, Republic of 817			X	
Yemen Arab Republic 678			X	
Yemen People's Rep. 680		X		X
Yugoslavia 345		X		
Zaire 490	X			X
Zambia 551		X		X
Zimbabwe 552		X	X	