POPULATION-ENVIRONMENT DYNAMICS: TOWARDS PUBLIC POLICY STRATEGIES

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PREFACE

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INTRODUCTION

This volume is a collection of separate but related studies focusing on the relationship between human populations and the environment. The dynamic linking population and environment takes many forms: one concerns how this dynamic can promote stability in the face of change. Thus, policy implications are critical. The effort consists of eleven chapters, each investigating a different aspect and geographic setting of the population-environment dynamic. In addition to this *general* theme, a particular framework for investigation is put forth. Namely, the notion that there are some specific attributes which help describe the dynamic and that these attributes exist across many sectors of society.

The organization of the document is as follows: first, we present the common framework, which we call a **family** of transitions. Electronic files offering color maps as bitmap files and electronic files supplying online analytic tools support the text. The eleven studies undertaken by individual investigators are presented, drawing upon the transitions framework and curve fitting tools. Finally, a concluding chapter is provided which relates the individual studies to each other, presents conclusions and suggests next steps in development.

Readers of the monograph reporting last year's work should note that the material in the following section on a family of transitions is repeated here for background and therefore can be skipped.

1. A FAMILY OF TRANSITIONS[1]

One way of viewing the complex dynamic relationships between population and the environment is to visualize them as a **family** of transitions. That is, not only is there a demographic and epidemiologic transition but also a deforestation, toxicity, agricultural, energy and urbanization transition as well as many others. In this chapter it is argued that for each transition there is a critical period when society is especially vulnerable. During that period, rates of change are high, societal adaptive capacity is limited, in part, due to this rapid change, and there is a greater likelihood that key relationships in the dynamic become severely imbalanced. The trajectory society takes through a transition varies, depending upon many factors operating at local and national levels. Transitions not only are occurring in many different sectors but also at different scales, both temporal and spatial. At times, a society experiences several transitions simultaneously, which can raise social vulnerability because of how they amplify each other.

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[1] This material was condensed from the original paper "Towards Building a Theory of Population-Environment Dynamics: A Family of Transitions," in *Population-Environment Dynamics: Ideas and Observations,* Ann Arbor: University of Michigan Press, 1993.

1.1 TYPES OF TRANSITIONS

The Demographic Transition

Let us begin with a review of the ideas behind the widely accepted demographic transition. At the onset of this transition, births and deaths are both high and are in relative equilibrium with each other. Historically, births exceed deaths by small amounts so total population rises only very gradually. Occasionally, famine or an epidemic causes a downturn in total population but in general, changes in rates are low. During the transition, however, death rates drop dramatically, usually due to a change in the health condition of the population. This change in health is caused by many, often interrelating factors. After some time lag, the birth rate begins to drop and generally declines until it is in approximate balance with the death rate again.

The Epidemiological Transition

The term epidemiologic transition was coined to describe the changing source of mortality and morbidity from infectious diseases occurring primarily in the younger age groups to degenerative diseases in older age groups. As with the demographic transition, there is considerable volatility during the transition. At the onset, infectious diseases begin their decline usually due to extensions of health care and sanitation by the national or local government. Single vector programs such as malaria control and immunization programs are often the first implemented because they are capable of ready extension and do not require as heavy a commitment to education and other sustained infrastructure - especially in rural areas. These single vector programs are then followed by broader-based health care which demand heavier investment in infrastructure. But an entirely successful move through this transition does not always happen. At times, other sectors in transition overpower the health care delivery system.

The Agricultural Transition

For several hundred years, worldwide agricultural production has been rising in relative harmony with population. Overall, increases in production have kept up with and even outpaced growth in population. The two factors that have been responsible for these increases are 1) extensions of land under cultivation and 2) improvements in productivity. At times changes have been dramatic. Formulating an agricultural transition reflects the condition that, in general, sources of increase in production shift from extending land to intensifying production on land already under cultivation.

The Forestry Transition

At the onset of the forestry transition generally a large percentage of a region is under forest cover. Rapid deforestation occurs during the transition and finally forest cover stabilizes at a lower level determined by many factors such as the local region's needs, the state of the local and national economy, climate and soil characteristics. In most settings this transition will end in a steady state equilibrium balancing growth and harvest. Again, how society handles the vulnerable transition period often determines in a profound way the quality of life for the region.

The Toxicity Transition

The toxicity transition can be considered a composite of many transitions: global atmospheric, local air pollution, surface water, ground water and solid waste to name a few. Again, there are at least two sets of factors operating in tandem. The transition begins with low levels of industrial or agricultural production and correspondingly low levels of toxins. As production and population increase, toxic byproducts increase to levels which eventually become unacceptable to the general public. This in turn, causes a public demand for pollution abatement. After an environmentally costly time lag, remediation steps are taken which help to bring pollution under control.

The Urbanization Transition

The urbanization transition is driven by the dual forces of rural to urban migration and central city population growth. The early stages of the transition area characterized by rapid growth of urban population; however, in later stages, growth declines and may reverse. Rural to urban migration is a product of many forces -- both "pull" and "push". In terms of the population-environment dynamic, the urbanization transition often acts as an amplifier as it interacts with other transitions.

The Fossil Fuel Transition

The fossil fuel transition is a special case of the energy transition. Historically, many energy transitions have already occurred in different regions and time periods. Significant transformations began in the sixteenth century brought about by sail and later, by steam power. Today, we are now in the most universal and perhaps critical energy transition: fossil fuels. Studying this transition is especially instructive because the record on different societies' passage through the vulnerable period is varied and appears to be heavily influenced by public policy.

1.2 GENERAL CHARACTERISTICS OF TRANSITIONS

Similarity of Trajectory Across Sectors

We have attempted to show in the seven example discussed earlier that the notion of transitions apply across all sectors of investigation. The classes of transition, from demographic, to toxicity, to forestry, to agriculture, to urbanization, to energy or to epidemiologic exhibit similar patterns. It is this perception that has caused us to posit the existence of a **family** of transitions possessing some common attributes useful in analysis. The first common attribute of all transitions is their trajectory. They all begin in reasonable stability, then move to the volatile transition period where change is rapid, and finally return again to relative balance. Analytically, these are clearly nonlinear systems but ones which have properties that lend themselves to well-understood mathematical functions.

Applicability of Transitions Across Scales

The second attribute has to do with scale. One of the most interesting and at the same time vexing aspects of studying population-environment dynamics is that many phenomena manifest themselves at all levels of geographical and temporal scale. For example, data depict one demographic transition for an entire continent, a different one for a country within that continent and still other different transitions at the regional level. Local conditions may delay or advance the onset and/or completion of the transition in relation to the larger body. Thus, moving through the demographic transition can take more or less time as the scale changes.

This same variation seems to exist in all other population-environment transitions that have been investigated. True, national or regional-level determinants often set the stage for the local dynamic, but in the end it is these local conditions which determine the timing, magnitude and specific trajectory of the overall transition.

One can think of our world, seeming to be chaotic, but instead consisting of a multitude of well defined transitions in many sectors, each with its own local characteristic. Different transitions begin at different times and places, but ebb and flow in an overlapping way, sometimes reinforcing one another and at other times dampening their dynamic. As adjustment occurs, occasionally useful niches are created which are then exploited by stressed elements of the ecosystem. Unfortunately, at other times, different sectors interact with each other in a harmful way to broaden and extend the susceptible period.

Societal Vulnerability

During transitions there seems to be a special vulnerability borne by society. Ample evidence indicates that the relationships are most likely to become out of balance during the transition. A primary cause of this vulnerability is the rapidity of change during the high velocity portion of the transition. Adaptive capacity is impeded because there is little time for systems to adjust and often there are limited feedback mechanisms operating which otherwise could help this process. Another contribution to social vulnerability during a transition is the amplifying effects created by transitions occurring simultaneously in several sectors. Rapid rates of change in several sectors could more easily overpower the available infrastructure which leads us to the next source of vulnerability during transitions: capital availability.

Capital or investment capacity can either amplify or reduce societal vulnerability during a transition. If there are financial resources available to deal with the effects of rapid change, remediation is easier to implement. Africa which is trying to deal with a difficult demographic transition has almost no capital available for its use and will therefore undergo great hardship. The Soviet Union and Eastern Europe are struggling to find financial resources to deal with their flawed toxicity transition. Another dimension of transitions which affects societal vulnerability is the degree of interconnectedness. How closely is the local village connected to the regional and national economy? How much does what happens in one location determine what happens in another? There is no question that interconnectedness is increasing worldwide. We also know that under some circumstances linkage creates dependencies which in turn, increase vulnerability. However, it can work in the opposite direction as well. These very same links to a larger domain can also act as a safety net. If there are connections, resources can be brought to the stressed area more easily to mitigate the local adversity. The final and perhaps most important dimension of transitions affecting vulnerability is feedback.

Analytic Properties of Transitions

We have seen that many characteristics of transitions are common across all sectors and geographic scales. The question then, is whether there are analytic techniques which might be useful in describing this family of transitions. If so, these techniques may be helpful in portraying transitions in a way that facilitates comparison and thereby increases our understanding. In this quest we are especially interested in techniques and functions which reduce complexity and at the same time provide a reasonably accurate portrayal of reality.

Functions which are candidates for consideration include exponential, exponential to the limit L, logistic, Gompertz, and the power function. Bounded functions which fit data more precisely but cannot be used for predictive purposes may also be helpful in uncovering patterns.

1.3 POLICY IMPLICATIONS OF TRANSITION THEORY

But what does it gain us to fit an exponential or logistic or for that matter *any* function to transition data? The answer lies in our ability to gain insights by relating different transitions to each other. First, consider the transitions *within* a given sector and at a given scale. We know there are transitions in a sector which some societies have already experienced while others have yet to endure. If the nature of these experiences can be captured in general form, it is more likely that knowledge can be transferred to other setting where a transition is first starting. Of course, each civilization or local culture has its own unique characteristics but any one emerging transition may be comparable to one or more of those which have occurred before because conditions are similar.

Second, there may be useful comparisons *across* different scales. We already surmise that a national-level transition, perhaps now in process, is actually composed of a myriad of local transitions also in process or which have recently occurred. But there may be other locales in the region for which the transition has yet to happen. If similar patterns emerge because of similar local conditions, a useful prediction could be made about the nature of the passage through the transitions yet to appear.

Third, there may be insights gained simply by the process of fitting a function to historical data. Different mathematical functions often have very specific underlying characteristics which can provide useful ideas.

The next potential use of transition theory is to facilitate analysis across sectors. There is, of course, no good reason to expect the trajectory of, say, a forestry or agricultural transition to mimic an epidemiologic transition. However, for any society at a given time, there may be similarities in the **rates** of change across sectors. Developed economies have slower rates of change in their agriculture sector than developing economies when conditions are favorable. Rural based cultures may be expected to have urbanization transitions which are steeper than non-rural cultures. In short, it is worth testing to see if patterns can be empirically determined which would be helpful in predicting the shape of future transition, given a stated level of intervention.

We have already mentioned the special societal vulnerability associated with several sectors being in rapid transition simultaneously. From a modeling perspective this simultaneity is a very difficult condition to describe and analyze, which may be why less progress has been made in this area to date. However, being able to portray these multiple transitions with specific functions could be helpful. There is no question that each transition interacts with the other. And to the analyst this means that a reliable model must be structured as a set of simultaneous relationships. Describing transitions as functions facilitates this manipulation.

Another potential benefit of transition theory lies in the identification of lead indicators. If success is achieved in fitting transition data to an appropriate function, then for a given condition and point in time, the future trajectory can be predicted more accurately. Identifying lead indicators is facilitated because with an orderly function, only one, or at most, two parameters need to be determined to define the trajectory. This advantage is even more evident when several functions are considered simultaneously.

Finally and perhaps most importantly, transition theory may permit more informed public and private intervention. At one level we find ourselves believing that the trajectory of a transition is somehow fixed by an immutable law of nature. But at another level we know that this is not the case. Public and private policy can make a difference as we have seen from some of the cases discussed in this book. Rates of change can be influenced by policy redirection and consequent resource allocation. To the extent that we can link historical rate differentials with historical policy implementation, a better determination can be made about which intervention mix works best in dealing with problems facing society today.

2. AN OVERVIEW OF THE INDIVIDUAL INVESTIGATIONS

Deborah Carr

The idea of stability in rural communities is the focus of this paper. It may seem profoundly obvious that rural communities have not, should not, and cannot be stable entities. It is not likely that anyone would argue that urban communities have been stable over the last century or even recent decades. Rural communities are subject to changing social, political, economic, and demographic forces, just as other communities (the nature of the impacts of these forces may vary across rural and urban areas, but their presence is felt regardless of location). The paper provides a broad overview of issues related to rural communities as well as the Forest Service's history with rural development and a discussion of what it has to offer to the understanding of rural communities. Data are presented which examine the relationship between socioeconomic well-being of rural communities and federal land ownership in the three Lake States of Michigan, Minnesota, and Wisconsin. The paper closes with a discussion of policy implications as well as suggested future research directions that may be fruitful for exploring change in rural communities.

Cheri L. DeRosia

This paper examines the population, urbanization, epidemiology, industrialization, and environmental toxicity trends in Thailand from the perspective of Drake's transition theory which holds that as a society modernizes it experiences transitions from relative stability through periods of rapid change, and then on to relative stability again. Even though Thailand is growing and changing it is reaching relative stability in its birth and death rates as well as its total population. The Bangkok area is very densely populated and dominates the growth projections for Thailand, but the country's population is still very rural with only 22% of its population living in urban areas. The urbanization trend in Thailand is well behind most developing countries in Asia and South America, especially if one compares urbanization to per capita GDP.

There are a number of indications that Thailand is at the end of its epidemiological transition, including low death rates for the young and a growing number of deaths caused by degenerative diseases in old age. Indications are that the epidemiological transition is probably as much due to increased economic prosperity during the 1980s and 1990s as to government health programs. Thailand has one of the fastest growing economies in Asia. Total GDP is projected to reach about 165 billion $US by 2000, with the manufacturing share increasing from about $11 billion US in 1984 to approximately $27 billion US. The industrial sector is growing in all regions of the country, but the Bangkok area receives the greatest number of new factories each year.

The economic prosperity in Thailand has come at the expense of the Thai environment. This study examines the levels of oxides of nitrogen (NOx) and sulfur dioxide (SO_2) emissions from manufacturing facilities present in the air. Although automobiles contribute a significant quantity of air pollutants, industrial SO_2 emissions are currently estimated to be more than four times higher than SO_2 emissions from transportation sources. Industrial NOx emissions are projected to increase to more than 350,000 tons per year, and industrial SO_2 emissions are estimated to increase to more than 1.2 million tons per year by 2000. Both NOx and SO_2 emissions are projected to rise faster than the manufacturing share of GDP if trends continue.

The Thai government has not been effective in dealing with the country's environmental problems, probably because the government has been relatively unstable over the past two decades. Growing support from the public may be effective in bringing positive responses from the government, but public support may only be available during times of crisis.

Rohinton Emmanuel

This study analyzes the urban climate and vegetative changes in Detroit, Michigan, in the light of its demographic trends. A comparison of two LANDSAT images made in autumn of 1975 and 1992 revealed a greening trend in the heart of Detroit. In view of its urban decay, it was suspected that such a trend might have climatic implications.

An attempt was therefore made to analyze changes in urban greenness in Detroit as a consequence of urban demographic changes. Greenness changes are quantified by comparing the two commercial satellite images mentioned above. A "Green Index" was developed by quantifying greenness change between these two images. All color increases in a given band above a certain threshold were coded green while decreases were coded red. No change in greenness between these two images (or changes less than the threshold) were coded black. The index was then computed by counting all the pixels in a given area displaying the color green and was expressed as a percentage of total number of pixels in that area.

Such changes are then super-imposed upon urban climate changes in and around the city. Trends in urban greening and urban climate changes are then grouped into phases of urban environmental changes.

A moderate logistic relationship was found between population change and urban greening in the city. Population decline up to a point lead to dramatic increase in urban greenness. No such relationship was found outside the city area. Urban night-time air temperature was seen to have dropped in the inner city while increases were seen in the growing suburbs.

The greening trends were then translated into indicators for urban socio-economic health of neighborhoods. More greenness (greater than 15% green pixels) was shown to indicate more devastated areas. Less greening (less than 4%) was seen as healthy neighborhoods. The rest were classified as transitional neighborhoods.

Finally, changes in the city are posited as possible lessons for efforts in urban climate mitigation in Detroit and elsewhere. Recommendations regarding quality of data needed for further study are also made.

Noah Hall

Coastal areas are of significant importance in researching the population-environment dynamic. Over one-fifth of the world's population lives in coastal areas, and this segment of the population is, on average, growing faster than the overall population. The coastal zone represents perhaps the clearest confrontation between human social and economic growth and the need for ecological conservation. The ecological stability of our planet's coastal and marine areas has direct impacts on human society. There is a clear and present need to protect coastal and marine resources and biodiversity. This paper explores the need to protect coastal and marine areas in the context of conservation.

Some countries are much further ahead in recognizing the economic and ecological benefits of protecting their coastal and marine areas. This paper examines some of the possible social, economic, and physical variables that characterize countries' levels of coastal protection. Over twenty such variables were tested, and none were found to be correlated to coastal protection. As examples, coastal population growth, per capita gross national product (G.N.P.), and percent of land area protected were examined. With no correlation evident, policy recommendations stress the need for consistent coastal protection on a global scale, using international agreements with set levels of protection.

Timothy Macdonald

The historic passage of the North American Free Trade Agreement is bound to have profound effects on all of the countries in the region. However, Mexico, as the least developed country of the three, is likely to experience the most dramatic changes. Mexico is currently in the midst of the demographic, epidemiological, and industrial transitions. This creates a period of vulnerability, in which rates of change can be extreme. The key to controlling the transitions will be the development of the Mexican bureaucracy, particularly the environmental enforcement. How Mexico begins to handle the increased pressure on the environment and human health will determine the conditions for the future. With the economic boost from NAFTA and increased cooperation with the United States in the border region, there is an opportunity to create a cleaner, healthier Mexico; however, without dedicated effort, Mexico will struggle through its transitional phases.

Soonae Park

Demographic phenomena, as the long term changes in births and deaths, are closely related to economic development. This relationship, however, is by no means uniform in different periods in history and in different countries. During the past three decades, the economic dynamism of Asia has been a focus of world attention. Annual growth rates of Asia's GNP have been higher than in any other part of the world. Commensurate with this rapid growth, the region's international trade has grown, and by the early 1980s the volume of US- Asian trade had surpassed trade between US and Europe (WRD, 1994). This dynamism exists chiefly in the free market economies of Asia. Three major factors have contributed to this dynamism: 1) demographic diversity and the different stages of industrial development that exist between Asian countries, 2) the common cultural background of Asia, and 3) the geographical proximity that these countries have with one another (Cho and Fujioka, 1986).

Asian countries have also experienced two kinds of major change: a demographic transition and an industrial transition. The former is characterized by the transition from high to low birth rates and from high to low death rates. The latter can be defined as the transition from an economy in which the agricultural sector predominates in gross domestic product (GDP) to one in which the share of industry, manufacturing, and services is predominant. Interaction between countries in different stages of demographic transition and different stages of industrial development generates economic dynamism by facilitating the transfer of capital and technology from countries that are at a more economically advanced stages to those that are less economically advanced.

Among Asian countries, Korea provides good illustration. With an initial population growth rate at three percent, the economy has grown at an annual rate of nine percent during the last three decades. During the same period, fertility has declined greatly. Also the rate of economic growth is high and demographic transition is fast. This level of sustained economic growth and this pace of demographic transition are in sharp contrast to the recent historical performance of the European countries. This paper will offer an interpretation of the structural changes in Korea's economy, within the broader context of Asian economic and demographic trends as outlined above. It will then provide some cross-country comparisons with Japan and other East Asian countries, which share a similar cultural and geographic background, but dissimilar with respect to initial demographic conditions and phase of economic development. Finally, I will suggest several policy implications that stem from this analysis of the Asian economic community.

Carlos de la Parra

The United States-Mexico border is a political boundary unlike any other in the world. It is home to almost 10 million people, of which slightly more than 4 million live on the Mexican side and slightly less than 6 million on the US side, and unites a highly developed, industrialized economy to an emerging, developing one. The cross-border differences in average income, language, culture, religion and political systems are among the most contrasting anywhere.

These differences are confronted acutely in twin border cities all along the border strip. The growth of an urban sprawl on any side of the border has proven to be the best promoter for development on the opposite side. Nine of these binational conurbations accounts for as much as 85 percent of the population living there.

After a period of stymied growth, the region experienced tremendous expansion in the 1980's. A manufacturing assembly-plant (*maquiladora*) program initiated in the sixties, grew dramatically in Tijuana and Ciudad Juarez. Commercial and tourist investments became profitable, industrial infrastructure was created and the "free commercial zone" was maintained allowing a duty-free flow in and out of foreign goods to the area. Population flows have followed the investment and employment opportunities that the area presents. For the young and growing Latin-American labor force, Mexico's northern border region has been a stepping stone to the promised land across the border, and a more developed and dynamic land of transition, heavily impacted by the US economy. It is an area that lures population, based on socioeconomic "pull" factors, that supported by "push" factors in southern states constitute a "***gradient***", analogous to gradients in the physical world, that creates the north ward population movement. Hence the growth rates of border cities reaching levels of 4 and 5%, while natural growth and fertility rates of the local population have decreased below national levels.

In attempting to use transition theory to assess the stability of the US-Mexico border region, it is my suggestion that our analysis should go beyond the demographic transition or the urban transition. This paper singles out a few factors which have produced the explosive population growth in the Mexican border cities, what the interaction with the United States is in terms of migration, and identifies the trends that these factors are following as they shape the future of border population. It is my goal to accomplish some comprehension of the stage of development in which the border region is in the present time, and at what point of its future development the rate of change in the area might become stable.

Brent Plater

Population growth has been cited as the ultimate cause of many environmental, social, and economic problems. However, few countries have taken the advice of population doomsdayers and implemented a population policy. The one notable exception is China. Throughout the past 40 years, the Republic of China has encouraged -- often coercively -- its population to stabilize its growth rate.

Although the policy was originally implemented to increase economic prosperity throughout the republic, the policy has also affected China's environmental quality. Emissions of sulfur dioxide, a principle air pollutant in China, have been reduced by 3% per year on average due to the population policy. Although countries using a direct approach to control air pollution have had greater success at decreasing emissions (i. e., the United States with the Clean Air Act), the population policy does show promise as a potential method for increasing environmental quality.

Although direct action policy is more effective at alleviating one particular problem, population policy has a broad effect across many problems. For less developed countries, this has profound policy implications. With a fixed resource base, a governmental institution would be able to mitigate several societal problems instead of correcting one problem while others go un-acted upon.

Unfortunately, the political climate in many nations is not favorable toward implementing population policy. Until the population/environment dynamic becomes a more salient global issue, few countries -- particularly in the first world -- will implement such a policy.

Shelley Price

As the South continues to develop, environmental degradation will excel at alarming rates. Due to the nature of the resource base and the quality of the land, this stress will not be easily handled. The ramifications of such environmental stress could be felt for centuries. If developing worlds follow the path taken be the current developed worlds towards environmental abatement through medium by medium, end-of-pipe regulation, the damage already incurred may be too significant to correct. Alternative solutions must be sought. A framework of pollution prevention and life cycle design would be appropriate in this case. This framework works within the market, not against it. As a result, economic growth is not ebbed as it is by more traditional regulations. There are some significant barriers to implementing a program such as this successfully in developing worlds. But alone with intraregional cooperation, following a set of guidelines can increase the successs of the program. With policy goals in place, pollution prevention and life cycle design can be integrated with other frameworks to cover the multi-faceted nature of transition to an industrial state, while maintaining the integrity of the environment.

Richard Wallace

Motor vehicles play a significant role in global climate change by emitting large amounts of greenhouse gases--especially carbon dioxide, which is an inevitable byproduct of fossil-fuel consumption. Currently, the developed nations are by far the primary sources of these emissions, but data suggest that the contributions of developing nations to this problem can be expected to increase steadily as their economies grow and they become more urbanized. Through the application of transition theory and the use of trend data, this paper closely examines vehicle-use patterns for six nations representative of population-environment dynamics throughout the world. The goal is to probe the efficacy of various policy options (including both technology- and behavior-based approaches) to control greenhouse emissions from the motor vehicle sector. Furthermore, an effort is made to tailor the policy analysis to the larger dynamics present in each nation. The analysis reveals that, despite current trends that appear bleak in regards to greenhouse emissions, each nation has available viable options to mitigate this emissions problem. In some cases, technology holds the promise of reducing greenhouse emissions significantly compared to current levels. The analysis also suggests that the window of opportunity for successful policy intervention may be quite short, indicating the need for swift action.

3. TRANSITIONS AND MATHEMATICS: FITTING CURVES TO EMPIRICAL DATA

We have seen that many characteristics of transitions are common across all sectors and geographic scales. They are all derived from actual numerical data and can therefore be considered logically from the vast array of theoretical perspectives offered by mathematics. Often, mathematics is used to model real-world data. When it is, typically, the mathematics is used to describe, either exactly or approximately, observed instances for which there is data. Then, the mathematics is used to make some sort of forecast as to the future status of the variables under consideration. A problem arises, however, when the reader passively accepts such forecasts on an equal footing with the part of the model that truly fits real data. When funding and policy decisions include projections as to future likelihoods, it becomes critical to know how forecasts were made and to have the opportunity to assess alternative futures using various mathematical tools. In studying transitions these tools facilitate comparison. In this quest we are especially interested in techniques and functions which reduce complexity and at the same time provide a reasonably accurate portrayal of reality.

Because any given data set can, in theory, be fit by an infinite number of mathematical "objects" (functions, relations, surfaces, and so forth), the participants were exposed to a wide variety of them. Mathematical models were fit to data gathered by seminar participants. Time was also spent discovering what kinds of fits had already been employed in published data sets that included projected data alongside actual data. Indeed, where linear curve fitting had been employed in these published data sets, it was illustrated how the forecasts in the table of data would change if an exponential or logistic curve had instead been fit to the actual data, and then extrapolated.

Because there were no mathematical prerequisites for the seminar, explanations were given using material required for a correct derivation (for those participants with sufficient mathematical background), and explanations were adjusted to give a broad overview and instructions for operating in a black-box mode for those with less exposure to mathematics. The array of topics provided to seminar participants is outlined in the next section.

I. Continuous Mathematics

A. Curve fitting

i. Bounded--useful for interpolation between observed data points. Forecasting is between data points. Not often used for extrapolation. Should give accurate fit to existing data points. Cubic spline interpolation. Derivation, requiring partial derivatives and linear algebra, provided.

ii. Unbounded

a. Linear regression. Fitting a line to a set of observed data--using software. Derivation of least squares line using partial derivatives.

b. Exponential. Derivation, beginning with laws of exponential growth and decay, and instruction of how to fit an exponential curve, independent of position of horizontal asymptote. The exponential was seen as but one example of a "power" function. The strategy employed was general and a thorough understanding of the derivation requires knowledge of the calculus through solution of differential equations by separating the variables.

c. Logarithmic. Done in conjunction with b.

d. Gompertz--this tool of the actuary, used in the preparation of life expectancy tables, was also presented as one S-shaped curve that appears in considering population dynamics. Computer software was used to make curve fit to data.

e. Logistic. Full discussion of theory. Also instruction on using computer.

f. Alternative ways of thinking about fitting--problem noted that least squares emphasizes role of outliers. Illustrated how to fit a line to a set of data using absolute value of vertical distance of observed value from line and how to fit a line to a set of data using the Euclidean metric.

B. Geometric Feedback and Chaos

i. Feedback--role of the line y=x in Feigenbaum's graphical analysis.

ii. Fixed points and their interpretation--repelling points serve to push process away; attractive points serve to pull it.

iii. Geometric dynamics--cycles in chaotic orbits--emphasis on the role of the horizontal asymptote as a "limit to growth." The mathematical possibility of curves crossing the horizontal asymptote mirrored the notion of going "beyond the limits" with alternative futures forecast by various mathematical models.

II. Discrete Mathematics

A. Systematic partitioning into mutually exclusive classes--a standardizing measure for transitions based on diagrams similar to those used for soil samples--transition profiles. Application to forestry transition graphs from Drake chapter.

B. Difference equations--used to illustrate one way to fit a polynomial to a data set. Useful for interpolation of real data sets.

C. Population doubling formula--derivation of precise formulation of the "rule of 70" and its extension for arbitrary population multiplication.

D. Atlas GIS software. Digital mapping is an application of discrete mathematics. There were several computer demonstrations of how to use each of these PC-based Geographic Information Systems. Topics focused on were the suitability of map projections and display strategies for different types of data. Students were also shown how to use GIS to interact with global databases so that data other than that provided could be mapped.