Chapter 12

VISUALIZATION

Exploring Growth and Development in the Global System

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Introduction

The purpose of this chapter is to highlight select features of current visualization technologies that are especially relevant to our understanding of globalization and the global system. If by visualization we mean "a method for seeing the unobservable," then information visualization has yet to acquire the status of mainstream methodology within the social sciences (Orford et al., 1976: 300). As yet, visualization has not enjoyed a strong, central, and coordinated research program to put forth visualization in mainstream scholarship – other than geography scholarship with a slow diffusion process often taking place from the "harder sciences" to the "softer sciences" (Orford et al., 1976: 300).

In his landmark text on the subject, *The Visual Display of Quantitative Information*, Edward Tufte puts forth the notion of *graphical excellence* referring to well-designed presentation of interesting data (1983). Graphical excellence spans issues of *substance, statistics,* and *design*, while giving the viewer the greatest number of ideas in the shortest amount of time with the least ink in the smallest space. It is nearly always multivariate, and excellence requires telling the truth about the data (Tufte, 1983: 51). This points to the importance of overcoming *perceptual impairment* since "graphics *reveal* data" (Tufte, 1983: 14). Tufte cites William Playfair, an eminent English political economist and a forerunner in the use of graphical designs, summarizes the ability for visual representation of information to facilitate the process between hypothesis generation and verification by overcoming perceptual impairment as follows:

> Information, that is imperfectly acquired, is generally as imperfectly retained; and a man who has carefully investigated a printed table, finds, when done, that he has only a very faint and partial idea of what he has

N. Choucri et al. (eds.), Mapping Sustainability: Knowledge e-Networking and the Value Chain, 231–260.

> read; and that like a figure imprinted on sand, is soon totally erased and defaced. The amount of mercantile transactions of money, and of profit or loss, are capable of being as easily represented in drawing, as any part of space, or as the face of a country; though, till now, it has not been attempted. Upon that principle these Charts [graphics] were made; and while they give a simple and distinct idea, they are as near perfect accuracy as is any way useful. On inspecting any one of these Charts attentively, a sufficiently distinct impression will be made, to remain unimpaired for a considerable time, and the idea which does remain will be simple and complete, at once including the duration and the amount (Tufte, 1983: 32).

At the same time, however, visual methods themselves are not without criticism. For instance, Tufte (1983) writes, that "for many people the first word that comes to mind when they think about statistical charts is 'lie,' 'the obvious to the ignorant,' or 'to protect the helpless dullards from crass graphical deception.'"[1] Although Tufte has outlined a methodological program for properly creating and usefully employing graphics in the natural and social sciences, he does not formally explain how the visual method is a distinct and valuable step in a general research design. In this chapter we argue that the visual method is an intermediate link between deductive theory and inductive analysis that generates feedback between qualitative reasoning and quantitative inference in scientific research.

12.1 Geographic Information Systems

One avenue of information visualization technology of increasing interest to understanding international relations is *Geographic Information Systems* (GIS).[2] By manipulating and retrieving spatially-referenced multivariate data, and linking the data to computer-generated maps, GIS allows the analyst to produce a variety of visual renditions and techniques through maps, while

[1] Professor Stephen M. Meyer of the Political Science Department at MIT once replied to this author on the subject of information visualization: "I wish I had something useful to say on the subject, but I don't. I use data visualization techniques when and where I think it helps the reader understand patterns in the data. That is, I use maps when maps help; I use graphs when graphs help; etc. The problem is most people cannot read graphs or maps." This opinion on information visualization is shared by many scholars and researchers in international relations, let alone political science, and his statement has provided a much needed critical outlook to this author in identifying the need for visualization in international relations.

[2] According to the Environmental Systems Research Institute (ESRI), the leading developer of Geographic Information Systems (www.esri.com), GIS is "an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information."

including a multitude of exploratory and quantitative tools for analyzing the data displayed on a given map. The traditional discipline of geography has embraced GIS technology throughout its present research program, and applied geography-GIS research has established its presence in environmental studies, earth and atmospheric sciences, urban studies and planning, and only more recently political science.[3]

12.1.1 GIS Applications

In the study of world politics, for example, Starr employs GIS and its accompanying spatial analysis tools both to operationalize and compute opportunity and willingness of geopolitical interaction (i.e. territorial trade, migration, or conflict), as well as to perform spatial statistical analysis of geographically referenced geopolitical data in order to quantify the effects of borders and distances in international structures and behaviors (2002). In the context of Lateral Pressure Theory in empirical international relations, Choucri has recently addressed the role of visualization for "exploring alternative representations of the global reality," and has undertaken initial applications of GIS technology for visual exploration of geopolitical datasets within geospatially-referenced structures. In a novel integration of GIS and AI (Artificial Intelligence) simulation, Koch uses GIS tools to provide a spatial computational engine and a framework for embedding simulated agents in a social networking space in order to analyze the influence of space upon agent-to-agent capabilities of interaction (Koch, 2005). Stephen Mathews, director of the Geographic Information Analysis Core of the Population Research Institute – which provides a larger collection (and monitoring thereof) of GIS implementation in political science – observes:

> There is evidence of an increased use of spatial analysis techniques within the social sciences generally, and for political science in particular. In part, the increased use of spatial methods arises from the increased mapping, visualization and spatial analysis functionality of GIS software. However, this trend is also driven by the increased availability of geospatial data on a variety of socioeconomic and environmental domains relevant to political scientists as well as the ability to couple advanced spatial statistical software with GIS software … (Mathews, 2002)

In sum, as Tufte suggests, the GIS visualization and the resulting geographics will help the researcher overcome the *perceptual impairment* of

[3] For a sample of journals related geographic work in the mentioned disciplines: *Annals of the Association of American Geographers*, *Climatic Change*, *Computers*, *Environment and Urban Systems*, *Economic Geography*, *GeoInformatica*, *The Journal of Urban Planning and Development*, *The Journal of Environmental Planning and Management*, *Geopolitics*, and *Political Geography*.

complex datasets by conveying "a thousand words [or data-points] through a single picture," a formidable task for comparative case narratives or a statistical table of results (Tufte, 1983).[4]

12.1.2 Basic Research Design

The social sciences usually deal with complex sociopolitical phenomena.[5] As a general statement, we can consider the overall "scheme" for research design in the social sciences to consist of two stages: the logical stage of theoretical framing and modeling on one hand, and the analytical stage of small versus large-N empirical methods on the other hand. Clearly, this is something of an oversimplification given the range of variations around this general representation. However, it does accurately reflect central tendencies in the social sciences. Hypotheses are framed and then accepted, rejected, or partially supported, and the results are assessed in order to decide how to improve or modify the underlying theory being tested. This general process is presented in Figure 12.1.

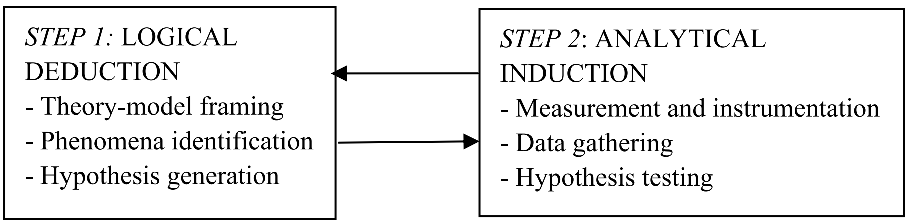

Figure 12.1 **Diagram of basic scientific research design.**

The view depicted in Figure 12.1 ignores the role of the human interface in making the transition from deductive logic to inductive analysis, and back again. But the human interface is an important feature of this process. Clearly, human cognition does not seamlessly and automatically translate ideas in the world of deductive reasoning to experiences and observations. Instead, the researcher enables interaction between reasoning and observation through a perceptual interface. This iterative process is not neutral with respect to the role of human, to their perceptions, and to their operational understanding of the underlying meanings. Information visualization becomes especially important in this context.

[4] For an excellent example of perceptual impairment, consider the problem of data exploration faced by climatologist Ralph Kahn of the Jet Propulsion Laboratory in Ball (2002).

[5] For a critique of large-N analysis in assessing complex causal processes, see Almond, with Genco (1977). Tufte also asserts this point in *The Visual Display of Quantitative Information.*

12.1.3 Topological Representation

Formally, the visual interface allows the researcher to comprehend logic and analysis via some intervening medium of perception. It attaches meaning to deductive and inductive results by *presenting* the results in a manner in which the researcher and observer can understand. To this end, this chapter argues that the addition of a third intermediate stage – *information visualization* – to the aforementioned scientific method provides a significant bridge between logical deduction, on the one hand, and analytical induction on the other. Logical propositions, proposed phenomena, and generated hypotheses are depicted in a visual medium by simulating predicted observations. Measurement, data gathered, and empirical inferences are also depicted in a visual medium in order to enable comparisons with simulated predictions. We refer to the formal relationship between logical deduction, the intervening stage, and analytical induction as one of *topological representation.* The rest of the chapter proceeds as follows:

First, we articulate a theory that prescribes sets of objects and their Cartesian product where all observable objects can possibly belong to and can be possibly related to each other (the scope of interest in a study). Logical propositions and generated hypotheses thereof then predict a subset of the Cartesian product (a relationship) in which the generated hypotheses expect objects under consideration to be organized.

Second, using visual representation then enables us to map the logical propositions of sets and relations to equivalent topological spaces, where relevant aspects of objects and their relations are represented by spatial features. For instance, a logical relation can correspond to a geometric surface inside a space, conveying information about how objects relate to each other (in terms of quantifiable equations) with geometric information (such as orientation, distance, curvature, area, volume, or connectivity).

Third, we then engage in applied analysis that takes the proposed logical relations and compares them to observed data, by comparing the analytical properties of the predictions to the analogous properties of the observations. For example, interval properties (i.e. increasing or decreasing, or concavity, maxima or minima) or functional parameters (i.e. linear, polynomial, or exponential coefficients) are assessed, and a likelihood of the success of a prediction is estimated (i.e. computing the square of the OLS Pearson product-moment coefficient along with the α-level of significance, or applying Mill's methods of experimental inquiry).

Fourth, through visual representation, observed data can also be spatially illustrated (in addition to predicted observations), and the topological features displayed using collected data can be used to reevaluate the theoretical predictions. Figure 12.2 shows key elements of scientific research design augmented by topographical representation. Figure 12.2 makes the functionalities of topographical representation explicit rather than implicit, and places the deployment of visual capabilities within the process of scientific inquiry itself.

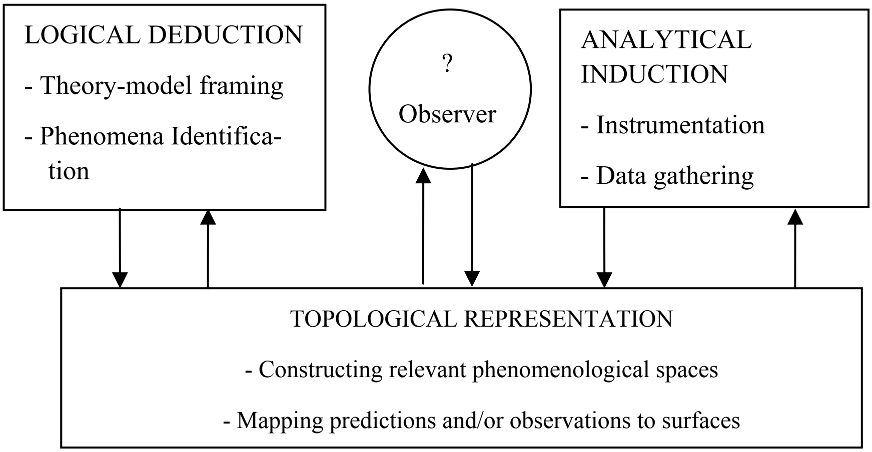

Figure 12.2 **Enhanced methodological design for general scientific inquiry.**

12.2 Visualization in Geopolitics: Case Studies

Of the many issue areas in international relations and world politics, few are as pervasive and compelling as issues pertaining to environment and development. Many scholars and policy makers argue that a balance is required between environmental conservation, economic development, and institutional performance and adaptability in order achieve "sustainable development."[6] In this context, we present a set of case investigations of data visualization in world politics, drawing on the theory of Lateral Pressure, and we illustrate how various topographical views provide different inferences and insights about the global system as a whole as well as its constituent parts.[7]

[6] Many definitions of sustainable development exist. The operating definition for this chapter comes from the 1987 Brundtland Report, where sustainable development is defined as "economic, technological, and political development which allows the needs of the present generation to be met without compromising the ability of future generations to meet their needs."

[7] For a recent review of the literature pertaining to Lateral Pressure Theory see Wickboldt and Choucri (2006).

12.2.1 The Theory of Lateral Pressure

Developed by Nazli Choucri and the late Robert C. North, *Lateral Pressure Theory* refers to the dynamics of growth and development of states in an international environment and posits that external behaviors – including environmental impacts – are shaped by the interaction among fundamental master variables. The master variables are defined as: (1) Population (P), the amount of people residing in, demanding from, and producing for a country. (2) Resources (R), the amount and accessibility of natural resources regardless. (3) Technology (T), or the level of economic productivity as a result of technological and organizational knowledge and skills. Different combinations of the P–R–T attributes generate different types of state profiles. Some of these are technology intensive, other population intensive, and still others are resource intensive. These differences generate commensurate differences in patterns of external behavior of environmental degradation.

Given that the three master variables are seen as the foundation for a country's capacity and intent to pursue particular social, economic, and political goals, it is interesting to explore whether these three measures, as independent variables (IV), can explain and predict the overall environmental impact of a country, which is the dependent variable (DV). Below we explain how P, R, T, and "environmental impact" are measured.

Lateral Pressure Theory argues that the dynamics of interaction are influenced by the capabilities of states, and these capabilities in turn can be "measured" or indicated on a first order approximation by the relative "positions" of population, resources, and technology (each variable's position being "measured" as a share or percent of the global total of the level of population, resources, and technology, respectively, that each country owns). As a consequence, the capabilities of states, a function of a country's relative position of population, resources, and technology, can explain and predict among other things the dynamics of conflict, migration, trade, and possibly environmental impact. Previous work in Lateral Pressure Theory operationalizes the "population position" of a state as its "percent of global population," the "resource position" as its "percent of global land area," and the "technology position" as a "percent of global GDP." We want to then visually explore how this theory organizes the IVs through profiles to explain environmental performance as measured through carbon dioxide emissions, a proxy for environmental impact, which is our DV.

By utilizing the GIS software to visually convey the basic message embodied in the data, we show in this chapter how the visual exploration of a large dataset with complex inter-relationships between variables, across a geographic space, and over time can expedite the process of hypothesis generation and testing. In particular, we will be visually illustrating the geographic distribution, temporal evolution, and cross-sectional inter-relationships of relevant variables, the categorical proxy of country profiles, and related variables of growth and development across all countries over a time frame of *several decades until the present.*

12.2.2 Highlights of Lateral Pressure Theory

According to Lateral Pressure Theory, interactions in the global political system are driven by these three different activities and conditions: "(a) the domestic growth and the external expansion of activities and interests [growth]; (b) competition for resources, markets, superiority in arms, and strategic advantage [competition]; and (c) the dynamics of crisis [conflict]" (Choucri et al., 1992). Moreover, Lateral Pressure originates from the interactions of key master variables that largely determine the properties and dynamics of nation-states: population, resources, and technology (Choucri et al., 1992). A brief characterization of key elements central to the case investigations of this chapter can be framed as follows:

Firstly, to the extent that a country has a greater *population*, more needs, wants, and demands are exerted upon the social and natural system (i.e. national institutions and natural resources). Secondly, to the extent that a country has a great level of *technology* in terms of applied knowledge and skills, a wider and greater amount of resources are required. Thirdly, to the extent that a country has access to *resources* via domestic extraction, the more or less constrained a country is in meeting its internal demands. Finally, given the relative levels of *population*, *technology*, and *resources*, countries can be roughly characterized into distinct categories or *country profiles*: for example, if country X has less of a global population share than a global technology share, and less of a global technology share than a global resources share, then country X belongs to profile A (Choucri et al., 1992).

A recent application and extension of Lateral Pressure Theory is presented in Lofdahl in *Environmental Impacts of Globalization and Trade: A Systems Study* (2000). Lofdahl adopted the theoretical and methodological framework of Lateral Pressure Theory to design a study concerning the effects of global economic activity upon the environment. He applies GIS, statistical analysis of geopolitical diffusion, and system dynamics simulations to conclude that North–South trade amounts to increased economic activity in the North in exchange to natural resource depletion in the south (Lofdahl, 2002). Lofdahl, however, does not characterize the three master variables in the same sense Choucri and North do; in particular, he acknowledges Choucri and North's concern that the three master variables can be further disaggregated into many intervening variables with confounding causal mechanisms and feedbacks.

At the same time, Lofdahl recognizes that there are specific aspects of the macrovariables (technology, resources, and population), which are themselves a refinement of Waltz's original variable-concept of power in international relations (Waltz, 1959), and a political analogy to land, labor, and capital – that are more important to examine than the mastervariables themselves (Lofdahl, 2002).[8] Therefore, Lofdahl adopts from Choucri carbon dioxide emissions as the key measure of environmental degradation (Lofdahl, 2002).[9] Thus, recognizing a strong empirical link between energy consumption and GNP, but at the same time pointing out a strong empirical link between net carbon dioxide inputs and deforestation, Lofdahl keeps GNP as his technology variable, but chooses forest stocks as his resource variable (Lofdahl, 2002). Accordingly, Lofdahl's re-characterization of the master variables also changes the concept of country profiles, appropriate to his study of environmental degradation. Against this background, we now turn to the exploration of global visualization, as motivated by the challenges posed by the theory of Lateral Pressure.

12.2.3 Visual Exploration – The Base Line

To commence our visual exploration, we start of with a view of the world absent of any political boundaries or superimposed data. The map in Figure 12.3 provides a frame of reference about the physical world we inhabit – up until now simply a celestial body in the solar system, whose foregoing map representation delineates land masses in gray and water masses in no color.

Aside from the fact that we can see land masses and we can infer water bodies, we can place no other judgments on the map above, save for the fact that some of us have taken geography and world history courses. In such a case, our mind immediately populates the map above with simple facts such as, "the map is centered about the Greenwich Meridian Line, which crosses through the continents of Europe, Africa, and Antarctica," or "the continents to the west are North and South America, and the remaining continents are Asia and Australia." We might also be tempted to identify additional regions, such as the Middle East, the Indian Subcontinent, the Mediterranean Sea (and adjacent coastal lands), the Far East, the Pacific Ocean, and others.

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[8] Choucri commented to the author that in refining Waltz's power variable to several key variables, the concepts of land, labor, and capital were theoretically and empirically recast in the international political setting as resources, population, and technology. Accordingly, the concept of country profiles was derived from these; in particular, technology was mostly left out from production function of the neo-classical growth model as an exogenous factor, later modeled as the cause of the Solow residual.

[9] Consider the central policy role of carbon dioxide emissions abatement in global warming debates as seen in the several UN global warming summits and COPs (Rio Summit, Kyoto Protocol, Hague Convention, etc.).

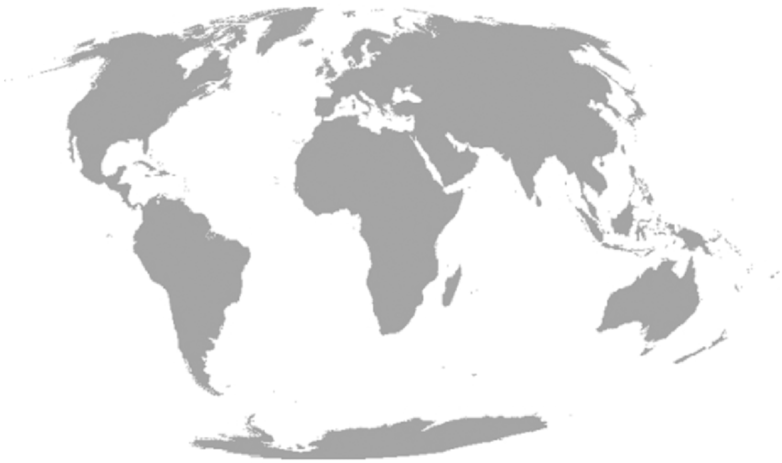


Figure 12.3 **A familiar map of the world.**

The dataset chosen to test the GIS implementation portion of this chapter is obtained from the Environmental Information Administration's *International Annual* (Grillot et al., 2002). From this dataset, we obtain the following measures for our variables of interest: (a) population: number of inhabitants (in millions); (b) resources: total primary energy production (quadrillion BTU); (c) technology: gross domestic product at market exchange rates (in billions of 1995 US Dollars); and (d) environmental impact: carbon dioxide emissions from the consumption and flaring of fossil fuels (in million metric tons of carbon dioxide). The dataset on world energy and global warming trends will serve as the case-study from which sample graphics will be produced and qualitatively assessed in anticipation of – not in lieu of – conventional small or large-N analysis that can be subsequently produced from the data.

12.2.4 Use of Shade and Two-Dimensional Maps

A simple geographic illustration of carbon dioxide emissions among countries in the year 2002 can prove quite useful. Aside from missing observations, we observe in Figure 12.4 the univariate geographic distribution of carbon dioxide emissions in equivalent carbon dioxide tons per country.[10] Two-dimensional color maps have been the standard of geographically-referenced data presentation for some time.

This map is shown firstly to convey a simple picture of carbon dioxide emissions for the year 2002. Top contending countries for highest carbon

[10] Several countries, including Argentina, Zaire, and Tanzania, had missing data.

dioxide emissions include the United States, followed by the former Soviet Union and China. Other than the facts that the United States is emitting somewhere between 4,600 and 5,750 million metric tons of carbon dioxide and the former Soviet Union and China are each emitting somewhere between 2,300 and 3,450 million metric tons of carbon dioxide, we also know that the rest of the countries are emitting somewhere between 0 and 1,150 million metric tons. However scarce in quantitative detail the map is, we already see carbon dioxide emissions in the year 2002 nontrivially distributed across the globe –heavily concentrated on the "big" three countries of the United States, China, and the former Soviet Union.[11]

Figure 12.4 **Equal interval five-shade stratum of carbon dioxide emissions per country for the year 2002.**

In Figure 12.5 we see the same data reclassified into 10 quantiles so that each shade corresponds to a 10% chunk of observations, with each shade being preceded by the previous tenth of observations and/or succeeded by the next tenth of observations.

The foregoing exercise on two-dimensional shading map creations served us a dual purpose. On one hand, we evaluated the specific strengths and weaknesses of different classification schemes of quantitative data into categories to be illustrated through shades in a map. As two-dimensional shade-maps are a mainstream option for illustrating geographically referenced data, it is of use to us to explore how different aspects of our univariate distribution of interest can be discovered or omitted by choosing different ways of

[11] Although the former Soviet Union undoubtedly is not a country in the year 2002, we include this former country as a relevant territory in our analysis given that we will be also inspecting a range of years starting at 1980.

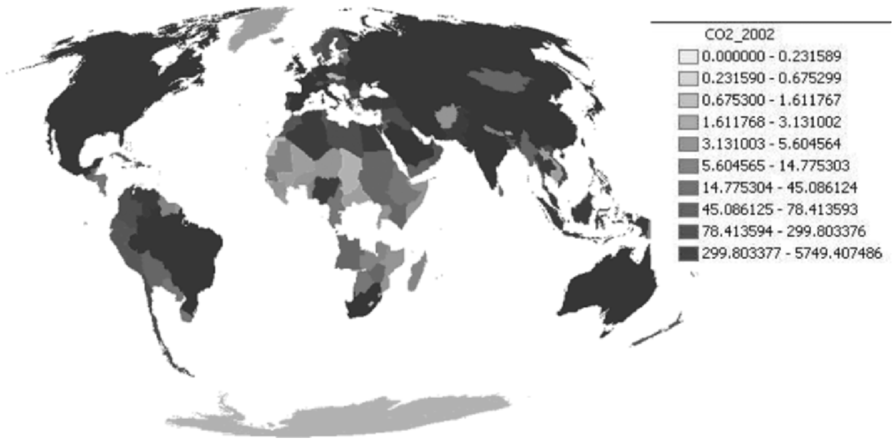


Figure 12.5 **Ten-shading quantile classification scheme for carbon dioxide emissions in millions of metric tons of carbon dioxide for the year 2002.**

categorizing the data. On the other hand, regardless of the potential gains of understanding derived from univariate displays by degrees of shading, we have concluded that using shaded (colored) maps to represent quantitative data is generally not the best way to go, in the sense that we wish to display the magnitude and direction of our quantitative data by recoding it into partially selective or meaningless categories (as illustrated through shade).

12.2.5 Three-Dimensional Map of Carbon Dioxide Emissions

In Figure 12.6, we see carbon dioxide emissions displayed in a three-dimensional map using height, by vertical extrusion of a country's territorial area upward into a volumetric figure. Similar to a bar chart, a country's height is now indicating the magnitude of an individual country's observation in the sense that the height of each country represents the magnitude of carbon dioxide emissions for the same country. Using height to represent carbon dioxide emissions, a scalar quantity (or specifically, *not* a categorical quantity), is a marked improvement over the use of color in the previous maps discussed here (and in general).

Notice that the particular way we chose to display carbon dioxide emissions – volumetric extrusion – extends the base area of a country to a height specified by the data producing a volume. This volume's height is accurately representing our scalar datum, yet the cross-section of this volume bears no information about the data. However, admitting the possibility for a person to misinterpret the volume of the extruded country as the visual proxy for a single data point, it then follows that the cross-section of the extrusion – namely the territorial area of the country – will distort a person's estimate of the magnitude of a scalar datum.

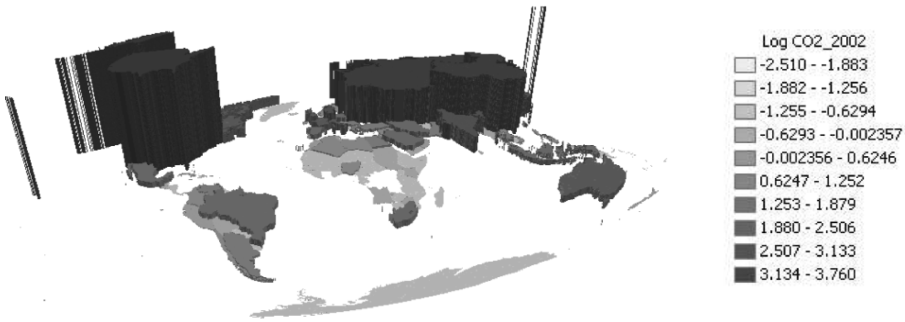


Figure 12.6 **Three-dimensional height (carbon dioxide emissions) and shaded (logarithmic carbon dioxide emissions) map for a univariate distribution of carbon dioxide emissions, 2003.**

For example in our last map, the former Soviet Union is lower in height but larger in area than China, so in our case, we may be lead to believe that the area of the former Soviet Union is giving us additional information about carbon dioxide emissions, when in fact it is not. If we were to believe that the resulting extruded volume represents carbon dioxide emissions (by thinking, for instance, that height represents carbon dioxide density, which also equals emissions per unit of area), then we may wrongly conclude that the Soviet Union, although lower in carbon density, emits on the whole more carbon dioxide than China.

What we should learn from this example is not necessarily to avoid confusing the volume for height when evaluating carbon dioxide emissions. Rather the message is that visual representation of data must done accurately and unambiguously in order to present the information of interest.

Focusing on the height of extruded country-shapes to evaluate the cross-national distribution of carbon dioxide emissions for the year 2002, we now turn to the substantive story behind the said distribution. We immediately notice from the shade maps and the height map that a great deal of countries show vanishingly small amounts of carbon dioxide emissions. Moreover, these countries are not randomly scattered around the globe, but rather clustered around different regions of the globe according to similar orders of magnitude. For instance, Africa shows the lowest set of values among all countries across the globe, followed by South America, Europe and Australia, Asia, and finally North America (particularly the United States).

Countries that stand out over and above the rest of observations include the United States, Japan, the former Soviet Union, China, India, Brazil, Australia, Germany, Saudi Arabia, Canada, Mexico, Iran, and others. Explanations immediately come to mind from our prior knowledge of social, economic, and geographic contexts of these countries – but we will delay any such discussion and examine more closely emissions over time.

Let us now look at carbon dioxide emissions from 1980 and 2000 to confirm whether or not this unequal distribution of carbon dioxide emissions across the globe for the year 2002 is a mere aberration occurring in that particular year.

12.3 Investigations of Three-Dimensional Map Displays

Extending our studies of topographical representation, we now turn to multidimensional map displays, with specific reference to the master variables in the theory of Lateral Pressure. The theory is anchored in the assumption that three sets of critical drivers best represent the characteristic features of states, namely population, resources, and technology. Accordingly we present a set of three-dimensional maps showing carbon dioxide emissions, the dependent variable, and the master variables – P, R, and T – as the independent variables, for each country worldwide at two points in time.[12] In each case we show the global patterns at two points in time, in 1980 and in 2000.

Figure 12.7 shows carbon dioxide emissions in 1980 and 2000. This variable is used here to represent environmental degradation in broad terms. Whereas height represents raw carbon dioxide emissions (in millions of metric tons), the eight shades are an equal-interval partition of logarithmic carbon dioxide emission values.

A visual inspection of the carbon dioxide emissions observations in 1980 and 2000 shows a remarkably stable geo-spatial distribution prevailing over time. The African continent, Europe, and South America showed trivial changes. Whereas the United States only experienced modest fractional increases in emissions, China showed a remarkably large increase in emissions, as well as more modest yet still noticeable increase in emissions from India. The former Soviet Union on the other hand faced a steady and noticeable decreasing trend in emissions throughout the two decades, eventually surpassed by China shortly after its dissolution.

Nevertheless, carbon dioxide emissions over the past two decades remained in a course of steady and slightly changing trends. More importantly, carbon dioxide emissions where heavily concentrated about a handful of countries and regions. We may conjecture then from Lateral Pressure theoretic considerations that this select sample of countries share any number of these traits: (a) they are relatively highly populated; (b) they are relatively resource abundant; and (c) they have relatively high economic outputs. By

[12] This is a summary representation of the results, since the entire record is developed on an annual basis in order to explore the potential contributions of topographical visualization to time-series analysis and inter-temporal dynamics.

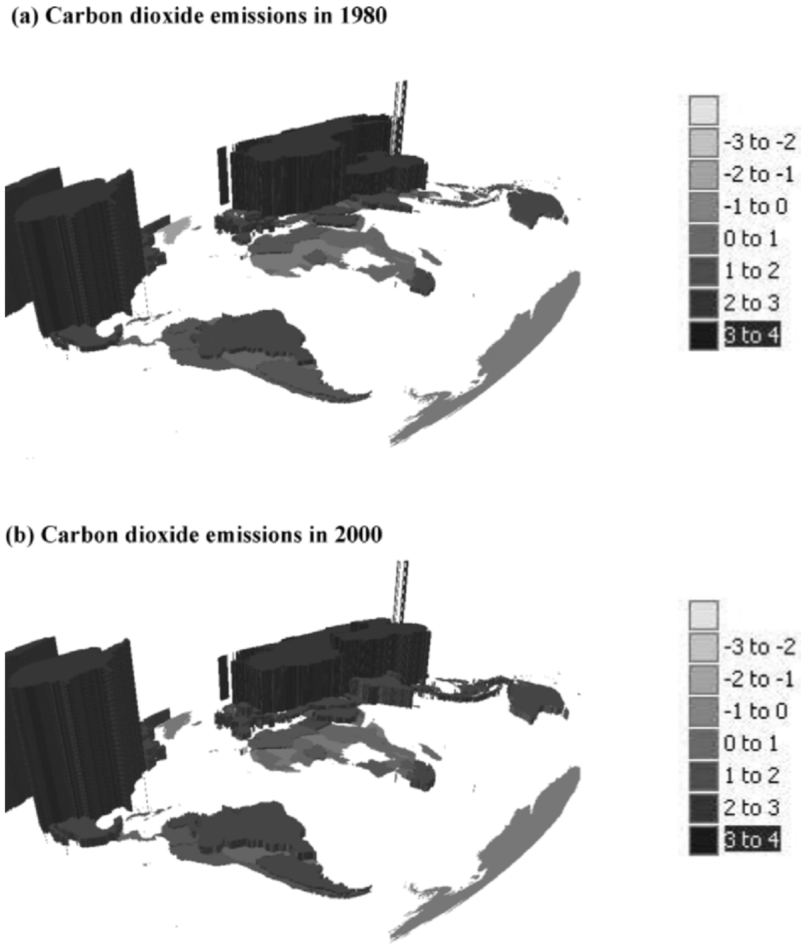


***Figure 12.7* Three-dimensional height and color maps for univariate distribution of carbon dioxide emissions, years (a) 1980 and (b) 2000.**

"relative" abundance or high levels it is meant that the share of population, resources, or technology (economic output) a given country owns from the global total is significantly larger than the majority of the other countries.

Instead of conjecturing from thin air what the population, resources, or technological levels of countries were during the same period, let us now turn to a visual inspection. Figure 12.8 shows the patterns of population in 1980 and in 2000.

It may come as no surprise that we see similar stable time evolution of our population, resources, and technology variables. Moreover, as we predicted from our Lateral Pressure hypothesis, the big countries controlled a significantly large portion of the world's population, resources, and technology.

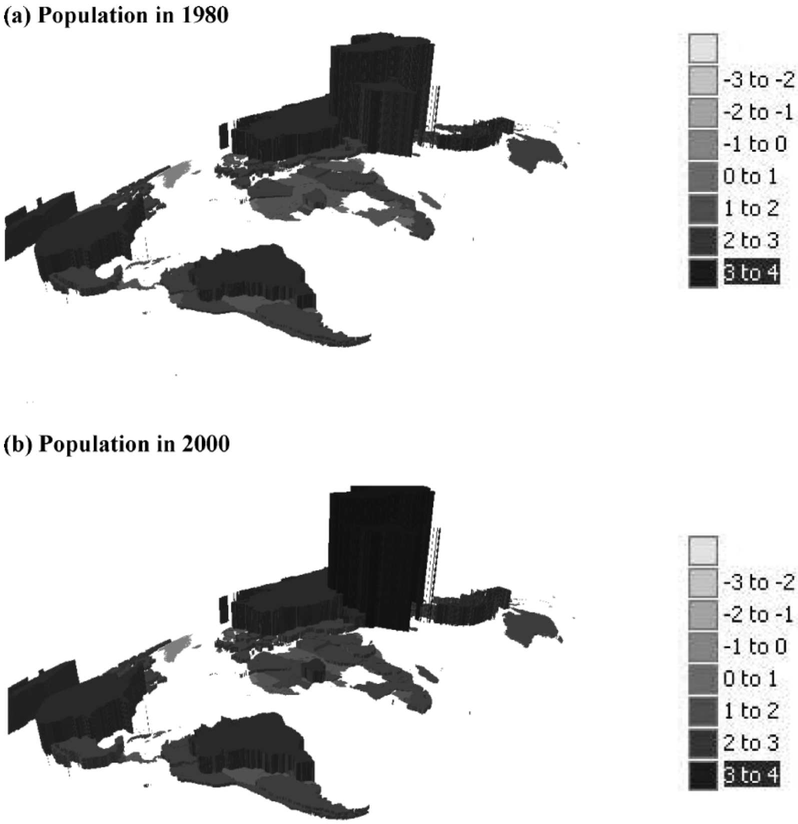


Figure 12.8 **Three-dimensional height and shaded map for univariate distribution of population across the world, years (a) 1980 and (b) 2000. Whereas height represents raw population values (in millions), eight-color spectrum is an equal-interval partition of logarithmic population values.**

Recall that United States carbon dioxide emissions slightly yet steadily increased from 1980 to 2000, whereas the former Soviet Union showed steadily yet significantly decreasing emission trends and China showed an explosion of emissions. India also showed some considerable increase in emissions given its initially low emission levels in 1980, and Japan showed high but relatively constant emission levels.

In Figure 12.9 we show the patterns of energy resource production worldwide. This set of visual representations is also put forth for 1980 and 2000.

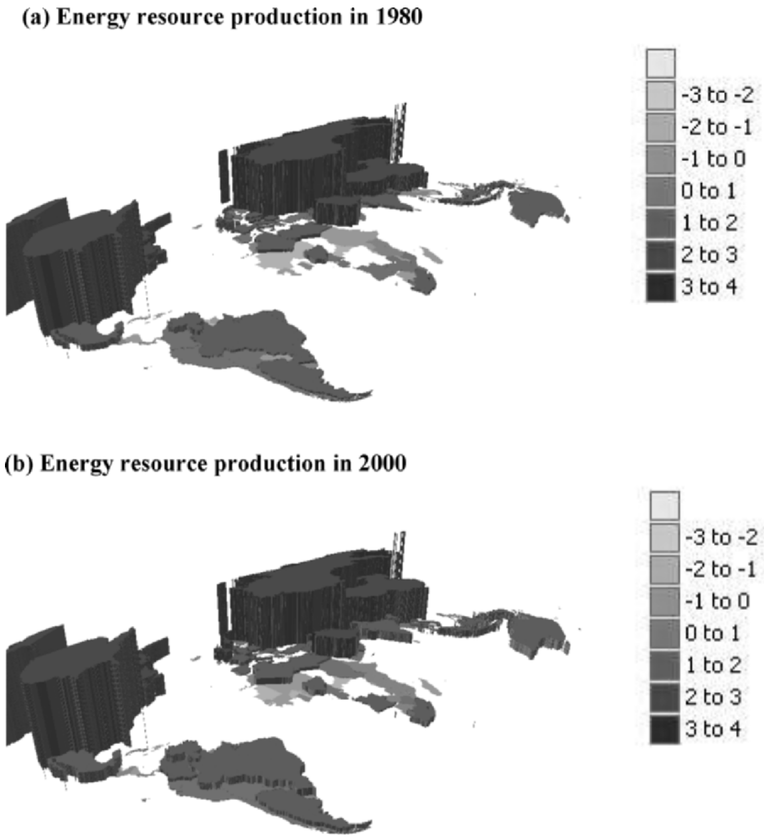


Figure 12.9 **Three-dimensional height and shaded map for univariate distribution of total primary energy resource production, years (a) 1980 and (b) 2000. Whereas height represents raw energy production (in Quads), eight-color spectrum is an equal-interval partition of logarithmic energy resource production values.**

Taking now these observations and comparing emission levels to other possible explanatory factors, we can immediately call to attention at least three sets of possible relationships. First, in the United States, China, India, and Japan domestic economic production, or technological output, grew substantially in this period, while the former Soviet Union's technological output decreased significantly, into its dissolution around 1992 and afterwards, as we can see in Figure 12.10. Second, in China and India the population increased throughout these decades; in Japan and United States population growth was much more modest. Third, resource production was mostly constant throughout the world, as it is most likely due to increasing discoveries in coal and natural gas reserves in this same period.

(a) GDP in 1980

(b) GDP in 2000

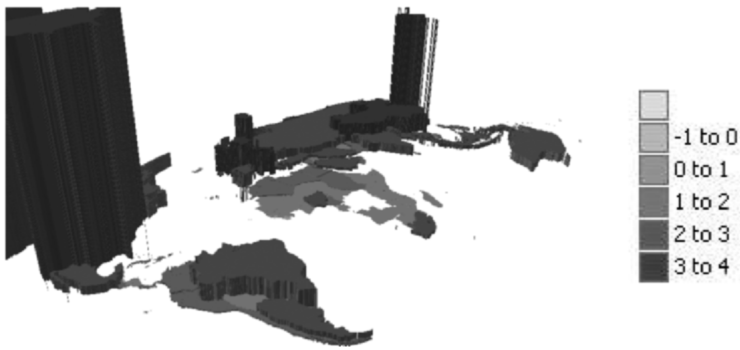


Figure 12.10 **Three-dimensional height and shaded map for univariate distribution of gross domestic production (technology as productivity), years 1980 and 2000. Whereas height represents raw dollar figures (in billions of constant US dollars), six-color spectrum is an equal-interval partition of logarithmic GDP values.**

12.3.1 Visual Display of Multivariate Relationships

Among the ways in which way we can visually inspect for multivariate relationships in the geographically referenced data is by producing a hybrid map/bar chart as shown in the previous figures. We can verily confirm that for our outliers of interest we have our Lateral Pressure explanatory variables systemically dominating carbon dioxide emissions. In some cases, like China and India, population intensity seems to heavily dominate its emission levels, whereas in other cases – like Japan and the United States – technological output heavily dominates carbon dioxide levels. Moreover, energy resource production levels for the various countries seem to be in the vicinity of corresponding carbon dioxide emission levels. Figure 12.11 extends the analysis in a pair wise comparison.[13] GHG stands for carbon dioxide emissions; POP stands for population; RSR stands for fossil fuel reserves; and TCH stands for technology (as measured by GDP).

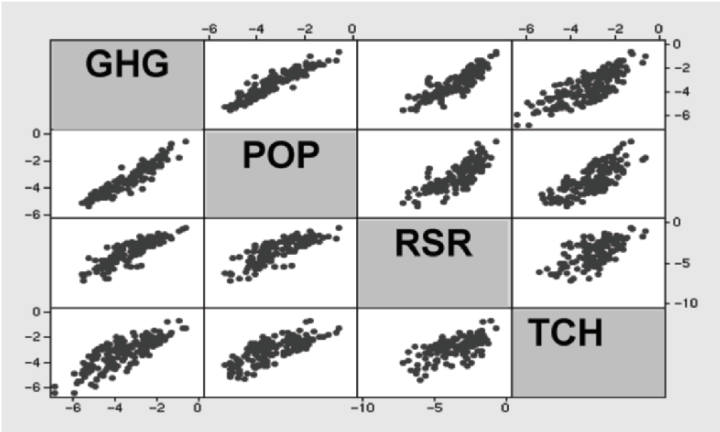


Figure 12.11 **A matrix of a bivariate logarithmic plot comparing population, resources, and technology to carbon dioxide emissions.**

These comparisons allow us to explore the strong correlations between explanatory Lateral Pressure variables and carbon dioxide emissions. We see in this matrix of bivariate plots that our chosen Lateral Pressure variables of population, resources, and technology strongly and positively correlate (particularly after a logarithmic transformation) with green house gas emissions across many orders of magnitude. The fact that the monotonous (almost linear) associations hold across many orders of magnitude implies that our previously ignored set of vanishingly small scalar observations, which consist a large part of our sample space, also support strong pair wise correlations between our explanatory variables and emission levels.

However, depending on which Lateral Pressure master variable dominates in size, we see a different explanatory variable dominating carbon dioxide emission levels for a given country – in other words, if a country is significantly more population intensive than resource or technology intensive (intensity measured as "percent a country shares of variable X from the global total), then population is going to primarily drive carbon dioxide emissions for that country.

[13] The matrix of bivariate plot would also allow us to inspect the rest of the observations across the globes whose values were vanishingly small in comparison to our few outlier observations, and hence left out of our text discussion.

12.3.2 Visualization of Carbon Dioxide Emissions across State Profiles

These conclusions from our visual exploration exercise thus set the stage for introducing the concept of Lateral Pressure profiles. The Lateral Pressure stipulation of the combinations among the master variables acknowledge relative differences in population, resource, and technology levels in determining Lateral Pressure impacts writ broad. We suspect that the relative ordering of intensities among three master variables resources, and bears a noticeable impact on a country's carbon dioxide emissions. Figure 12.12 shows the patterns at two points in time. These trajectories suggest a pattern in carbon dioxide emissions across profile groups.

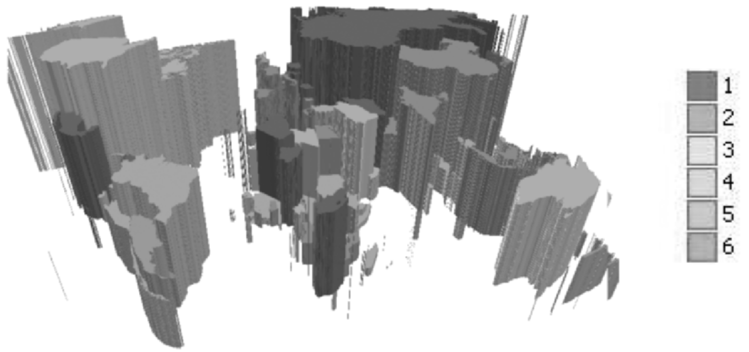
We can tell that generally, the more technologically intensive a profile of some country is, the higher we can expect their carbon dioxide emissions to be. Moreover, among low technologically intensive countries (that is, where the countries are more population and resources intensive than technology intensive), being relatively more populous than resource abundant leads to greater emissions on average (except for the year 1995). For countries in profiles of medium to higher relative technologic intensity, being more populous than being resource abundant leads to lower carbon dioxide emissions on average.

We can account for these observations in several possible ways. Up until the early 1990s, we can suspect that countries with low technological levels largely consist of labor-intensive economies with a strong dependency on agriculture and polluting manufacture sector and with correspondingly smaller developments in the service sector. Hence larger populations are going to increase the level of carbon dioxide emissions resulting from employment in agriculture and in "dirty" industries.

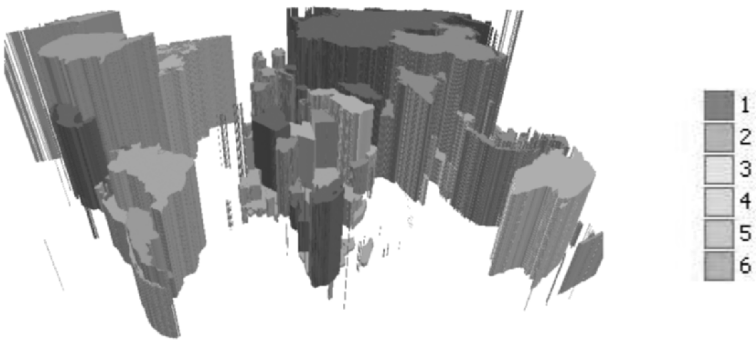
With the development of service economies into the later years of the 1990's, coupled with more mature industry sectors, national economies are now more reliant on energy production and less on labor for the production of goods and services. Hence in later years, more resource intensive countries – that is, countries with higher energy production from conventional fuel stocks (i.e. fossil fuels) relative to their population intensity ($R > P$) will end up releasing more carbon dioxide emissions into the atmosphere (by as much as half to an order of magnitude on average).

Setting aside impacts on carbon dioxide emissions from relative differences in population and resources, we expect that countries with higher technological output (measured as GDP) relative to either or both population and/or resource levels will show substantial increase in carbon dioxide emissions. Technological output, qualitatively defined in Lateral Pressure Theory applications of knowledge and skills, managerial and organization – and

(a) Carbon dioxide emissions in 1980



(b) Carbon dioxide emissions in 1995



(c) Carbon dioxide emissions by profile group

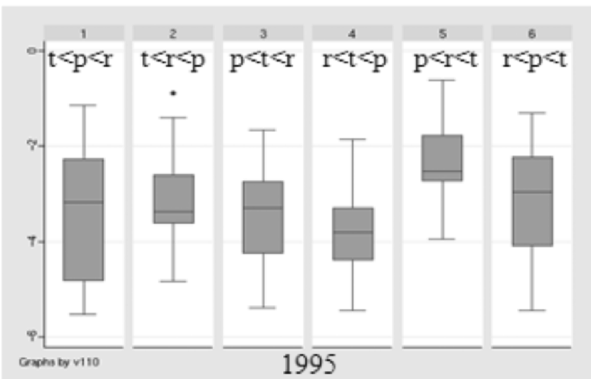


Figure 12.12 **Categorical comparison of carbon dioxide emissions (log) against Lateral Pressure profiles, (a) 1980, (b) 1995, and (c) a single box-whisker graph from 1995. Values in the 25–75% percentile range are inside the box, with the horizontal line inside the box representing the median observation. The "whiskers" or tails show the 10–90% range of observations, whereas dots plotted beyond the whiskers are considered outliers.**

hence indicated by level of production – will have a strong effect on carbon dioxide emissions as economies are increasingly more reliant on fossil-fuel derived energy sources for economic growth. Hence those countries that are more technologically intensive than they are population and resource intensive show a disproportionate increase in emission levels on average. Countries that are dominantly population intensive or resource intensive on average will not show nearly as much emissions as countries with dominant technology intensity.

We can thus conclude, in advance of any hypothesis testing and confirming what we have learned from our foregoing visualization exercise, that the explanatory variables afforded from the Lateral Pressure perspective largely dominates global carbon dioxide emission trends, both through the influence of relative intensities captured by the categorical profiles, as well as through the separate contributions of each explanatory variable upon our dependent emissions variable. These conclusions, inspired by the visual exploration exercise narrated above, can also be analytically confirmed through statistical hypothesis testing. More importantly, however, is the fact that our visual inspection of emissions and the three master Lateral Pressure variables revealed that geography implicitly but substantially influences global green house gas emission patterns.

The master or explanatory variables afforded from Lateral Pressure Theory, which heavily influence carbon dioxide emissions, face serious constraints within the underlying geographic space. Certainly energy resources, people, and goods and services flow across borders in an increasingly more interconnected global system. Nonetheless, factors of growth within territorial borders are largely endogenous and determined by internal social, economic, and institutional factors.

Population growth is still largely due to internal birth and death rates (with migration facing greater barriers face to face with heightened security concerns and increasing military sophistication). Moreover, resource production is largely predetermined by the abundance of fuel types within territorial borders. Finally domestic economic production (technological output) is largely determined by domestic factors of production such as a skilled labor force and physical capital.

Coupled with the fact that our Lateral Pressure explanatory variables change at most a few percentage points year after year, carbon dioxide emissions as a result will show a gradual time-evolution with relatively stable heterogeneous geo-spatial distributions (as we saw from the carbon dioxide emission maps). Hence, in the discourse of global warming policy investigation, a country's location in the world will significantly factor into the domestic Lateral Pressure factors that will dominate green house gas emissions yesterday, today, and well into the future.

12.4 Conclusion and Next Steps

In this chapter, we have introduced the concept of topographical representation and explored visually the data relevant to the case study in geopolitics. Specifically, ArcGIS – a GIS program – is employed to illustrate the results obtainable from a server-client solution, capable of retrieving data from a geopolitical database, obtaining user display options, and accordingly produce maps visually rendering the geopolitical data subset. Several visualization techniques, or modes in which to display the same kind of data, are treated and critically assessed for utility and relevance given the type of data at hand. We find that non-stochastic distributions in our main explanatory variables – population, technology, and resources shares – exist across the globe. Since the explanatory variables do not change in a volatile fashion for each country year after year, and given that green house gas emissions strongly depend on these variables, we find that basically most countries experience a consistent albeit gradually evolving pattern in green house gas emissions over time – as illustrated by similar cross-sections of emissions across the globe at each point in time.[14]

By way of conclusion, we first point to several venues for capturing the added value due to visualization technologies and applications. Then we propose, tentatively to be sure, key features of an approach for the design and development of a server-client application for GIS.

12.4.1 Value Added Due to Visualization

Here we consider the potential gains due to visualization, addressing in sequence some key conceptual, empirical, and inference issues. Then we put forth an integrated view of the added value as the pieces are pulled together. The integration, however, is contingent on the contents of each of the three sets of issues therein.

12.4.1.1 Conceptual Value

A rough guideline for implementing information visualization in general science research can be sketched from our foregoing theoretical discussion. It is hard to commence any scientific work without some initial conception and perception of a problem. Assuming we have identified a problem and a

[14] A major dilemma arises, of course, when countries break-up (such as the former Soviet Union) and the challenge is to then generate the commensurate visualization representations for the new states defined by new territorial boundaries. Exploring this contingency remains outside the scope of our investigations in this chapter.

set of related experiences, what follows is a description of an iterative procedure of visualization, deduction, and induction.[15]

From our set of observations and problem identification, we first construct a set of observables, more commonly known as data, which we can translate into a perceptual (visual) medium. How exactly can we conceive of a "visual translation" for a set of observables? It usually starts with how we first perceived our set of observations from prior experience. If we are analyzing political behavior, what we initially perceive is literally people voicing the concerns in the media followed by political commentary in the news. However, to proceed into theoretical deduction and empirical induction in order to organize our experience into systems of thought, we probably want to simplify how we perceive our set of observables. For instance, analyzing millions of hours of raw video footage of people expressing their political opinions is probably a very time-consuming task that will lead to not as comparable progress in scientific research – but raw video footage is certainly a start for visualizing a set of observables.

Then we proceed to theoretical deduction where we may review previous related theories or come up with new theories. To proceed to this step, we visually explore the data in the previous step to determine what emerging relationships exist among our observations. Given that we at least start with a problem identification (and a possible prior theory), and some natural abilities at describing observations, we identify from our visual exploration qualities about our observations that hint towards some sort of relationship.

Returning now to deduction, we motivate the generation of new theories or modification of old ones related to our identified problem through the visually or perceptually identified relationships, and even generate testable hypotheses or predicted observations which can be visually imagined in order to compare to present observations.

12.4.1.2 Empirical Value

Following this logic, testable hypotheses can then be empirically verified against observations. That is to say, whatever relationships a hypothesis claims about the way observations are behaving in the real world can be compared to actual observations through qualitative or quantitative analysis. Ideally, the analysis will determine the likelihood or probability that a prediction matches what is really going on among the set of observables. This likelihood or probability is the generalization of how true or false our hypothesis or prediction is when applied to our actual observations.

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[15] In this discussion, we do not seek to derive an explanation of what consists of problem identification or a set of related experiences – these are deep questions concerning the philosophy of mind and science that shall not be explored here.

Assuming that the test for a hypothesis is constructed properly by the researcher, statistical analysis can readily provide results on such likelihoods. In our example on video footage where we interview people about their political opinions, it might be very hard to construct a robust statistical test that confirms the existence of social networks between people who have similar political beliefs; it might be easier to conclude though the likelihood of a correlation existing between left-right ideological stance and income (among other possible variables).

Results from our hypothesis testing return us to the other two stages: hypothesis exploration (visualization) and generation (theoretical deduction). Having an idea of the likelihood of our recently tested hypothesis allows us to reevaluate our supporting theories by updating the truth values of logical claims and implications as they propagate through our network of knowledge.

For instance, our theory formerly depended heavily upon the assertion that people who had plenty of political opinion have strong religious beliefs and that the presence or lack thereof of religious beliefs is strongly connected to financial prosperity. A hypothesis test confirming the likelihood of any of these statements is going to update our knowledge about political behavior and hence modify the falsehood or fallacy of several predictions belonging to our theoretical framework of political behavior.

12.4.1.3 Inference Value

Accordingly with our new found knowledge, we return to the drawing board on how to perceive and interpret our observations. In particular, we may decide that certain qualities about our observations are not as important, and therefore we must seek new explanations driving the phenomena we are studying. Hence we redefine the scope of our visualization to include or exclude certain aspects of our experience as represented by a set of observables and seek new patterns and relationships based on our newer rendition of the observations available to us. Through continued exploration we may eventually identify new possibilities on how our observations seem to organize and return to our theoretical stage to frame our exploration of observations into formal hypotheses, and so on.

By way of delineating a manner for scientific inquiry involving methods of visualization, we propose a six-step process.

1. Identify prior notions of problem along with related explanations (theories) and experiences (observations) to determine what aspects of our set of observations we are interested in visually representing.
2. Relationships are identified from visual exploration of observations for subsequent theoretical framing.

3. Hypotheses are generated from theoretical framework for empirical verification of likelihood.
4. Simulated predictions from generated hypotheses are produced for qualitative visual rendition.
5. Simulated predictions are qualitatively compared to actual observations in preparation for likelihood test.
6. The likelihoods that simulated predictions from our hypotheses match actual observations are assessed, updating both our prior understanding of the problem (theories) and how we judge prior experience (observations).

Figure 12.13 illustrates this process of scientific inquiry, which cycles through information visualization (hypothesis exploration), theoretical deduction (hypothesis generation), and empirical analysis (hypothesis testing). The corresponding numbers show the six-step process next to the arrows where each step takes place.

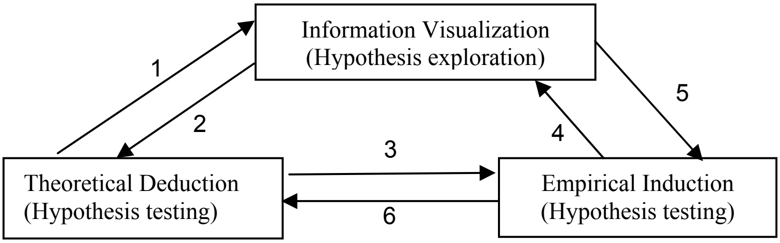

Figure 12.13 **Diagram illustrating the process of scientific inquiry from visualization to deduction to induction – and back again through the same process.**

12.4.2 Design for Client-Server Visualization System

Future work extending upon the proof of concept for visualization specifically in the area of geopolitical research suggests a design and development of a server-client application for GIS, which will automate the visual inspection of predictions and observations as pursued in this chapter. Accordingly, we now propose the feasibility of such an endeavor by providing a conceptual design of a graphical user interface that mimics the various visualization techniques on the user-end machine explored in this chapter.

At the core of a Geographic Information System's functionality is the ability to visually represent geographically-referenced information as maps. In addition, GIS implies the involvement of computers, developers, users, and methods to simulate, explore, analyze, and act upon the information which is being visually produced in maps. In the domain of geopolitics in International Relation, relevant research data resides in a geographic space – in the sense that individual observations correspond to geographic locations or features. To this end, the challenge is to better explore visually the geo-spatial dependencies of observations about attributes or behaviors of entities interacting in the global system (i.e. "how are trade or migration patterns related to geographic distance between cities or length of contiguous borders?").

12.4.2.1 Elements of a GIS Client-Server System

In the server-client GIS solution, the Graphic User Interface (GUI) client allows: (a) navigation of visual renditions on user display to spatially locate features and data records; (b) manipulation of visual rendition of data for research purposes and qualitative treatment; and (c) analysis of data by exporting data, generating additional graphic displays, or performing real-time quantitative computation. Moreover, GUI client interacts with GIS server by sending data requests and display options. The GIS server is then responsible for: (a) retrieving data from repository dataset; (b) linking retrieved data to relevant map layer files; and (c) generating map projections according to user-specified display options. Finally, the GIS server sends back visual data output to GUI client for display and further user interaction.

The client, on the other hand, is an user-end application that provides the human-machine interface, i.e. in the form of GUI, in order for the user to remotely request the data off the sever, display the data through several different options in his local screen, and interact with the data on his or her end.

The server-client application concept in itself is not new and this author is certainly not innovating upon this particular feature. The server to be developed for future work is quite simply a machine that will contain both the data to be retrieved, as well as the software tools (i.e. scripts and run-time server environments) to generate visual renditions of the said data. From the perspective of global analysis and/or social science research program, servers fulfill the need of storing datasets or databases of real-world observations or simulated data, coupled with the software necessary for accessing the data, in order to carry out the relevant quantitative analysis required to test hypotheses in political science research.

12.4.2.2 Learning-by-Exploring

The learning curve for typical data GIS application development would otherwise make the prospect of generating customized GIS applications for visually analyzing the data for navigational and analytical interaction unattractive and complicated. A user-friendly GIS application will essentially permit the prospective user to focus on generating a model of the global reality and explanations of how data is structured and interacting, and accordingly confirm expected patterns and behaviors by observing visual representations of the data and empirical results through the interface – instead of becoming experts in data visualization tools and techniques. Thus, the visual data exploration performed in this thesis will serve as a proof of concept or demonstration of how a GIS server-client solution customized for geopolitical studies could facilitate identification of underlying relationships in the data for the researcher-observer, by decreasing the computational complexity of exploring, formulating, and testing alternative hypotheses in geopolitical research.

12.4.2.3 Added Value

The value added is a synergistic result of the several components of such a final application. On the server side, geographically-referenced datasets will be collected for this thesis (although a server not formally developed) and made available for interaction with the client interface. With all the data preparation done beforehand, the user's primary concerns are to retrieve the data, choose display settings depending on personal preferences, and generate a visual rendition of the requested data for data exploration. On the client side, pre-existing GIS applications (such as ArcGIS used in the analysis in this chapter) are available to the user such that he or she does not have to be concerned with the programming code to generate visual renditions of the data.

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