The International Futures (IFs) Modeling Project

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Since 1980, the International Futures (IFs) project has produced three generations of the world model with that name. The IFs model facilitates analysis of global demographic, economic, energy, agricultural, environmental, and sociopolitical systems into or through the 21st century. The most recent release within the third generation provides detail on more than 200 variables across as many as 20 different countries and regions. IFs has increasingly evolved from a global model to a global modeling system that allows analysis of data and analytical relationships across 162 countries. The system runs under Microsoft Windows with a menu-driven structure for simplified scenario analysis. IFs is widely available for educational use and policy analysis. The primary focal points of analysis with IFs are (a) elements of the possible transition toward sustainability in the 21st century, and (b) aspects of sociopolitical change within countries and in the global system.

KEYWORDS: *demographics; energy; environment; food; forecasting; futures; global change; international futures; political change; simulation; social change; sustainable development; world modeling.*

International Futures (IFs) is a world model or computer simulation of global development that

- divides the world into geographic regions (up to 20 different countries or aggregated groupings of countries from a database for 162 countries);
- represents the dynamics and interactions of demographics, economics, food systems, energy systems, selected environmental systems, and elements of sociopolitical change;

AUTHOR'S NOTE: The author gratefully recognizes many critical contributions to the development of International Futures (IFs). Much came from members of two world modeling projects: (a) the inspiration and ideas of Mihaljo Mesarovic, Aldo Barsotti, Juan Huerta, John Richardson, Thomas Shook, Patricia Strauch, and other members of the World Integrated Model (WIM) team; (b) the scholarly contributions by Stuart Bremer, Peter Brecke, Thomas Cusack, Wolf Dieter-Eberwein, Brian Pollins, and Dale Smith of the GLOBUS modeling project. Across the generations of IFs, I have received much help and many suggestions from (among others) Donald Borock, Richard Chadwick, William Dixon, Elizabeth Hanson, Curtis Johnson, Dale

- uses a dynamic, equilibrium-seeking structure that allows simulation as far into the future as 2100;
- sits within a menu-driven modeling system that allows easy development and exploration of alternative "if then" statements about the future (hence the acronym IFs); and
- allows extensive cross-sectional and limited longitudinal analysis of relationships among hundreds of variables across 162 countries.

The structures of International Futures consciously build on the features of many other global models developed since the early 1970s. Because IFs is inexpensively available for educational or other use (accompanying a book by the same name), it makes such world modeling accessible to a wide audience.

IFs provides its users, both students and policy analysts, with the ability to explore a variety of potential global transitions. Transitions in the 21st century need to move much of humanity toward environmental sustainability and are likely to move most of humanity to social conditions that now characterize only economically advanced countries. The model helps its users investigate the sensitivity of such transitions to an extensive range of assumptions about the dynamics of the underlying systems and about possible policy choices.

This article will (a) trace the history and lineage of International Futures, (b) provide greater detail on its structure, and (c) illustrate the analysis that a user can undertake with the model.

History and Lineage

The first generation of IFs simulation appeared in 1980, shortly after the publication of *World Modeling: The Mesarovic-Pestel Model in the Context of Its Contemporaries* (Hughes, 1980). Drawing upon that comparative analysis of world models, IFs consciously integrated content and structure from several of the most widely known world models that appeared following the pioneering simulation of Forrester (1971) and Meadows, Meadows, Randers, and Behrens (1972). Specifically, IFs drew on the Mesarovic-Pestel or world integrated model (Mesarovic & Pestel, 1974), the Leontief world

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Rothman, Phil Schrodt, Douglas Stuart, Donald Sylvan, and Jonathan Wilkenfeld. Michael Niemann, Terrance Peet-Lukes, and Douglas McClure helped with microcomputer adaptation. James Chung, Padma Padula, Shannon Brady, David Horan, and Michael Ferrier helped with data and in other ways. Harold Guetzkow, Karl Deutsch, and Gerald Barney have long provided generalized support and useful guidance. Finally, the National Science Foundation, the Cleveland Foundation, the Exxon Education Foundation, the Kettering Family Foundation, the Pacific Cultural Foundation, and the United States Institute of Peace all contributed essential financial assistance, but should never be held responsible for the evolving product.

model (Leontief, Carter, & Petri, 1977), the Bariloche Foundation's world model (Herrera et al., 1976), and Systems Analysis Research Unit (SARU) model (SARU, 1977). CONDUIT, an educational software distribution center at the University of Iowa, distributed IFs in FORTRAN for use on mainframe computers.

Although the first generation of IFs was intended primarily for educational use, all generations (and especially the third) have also attempted to provide policy analysis capability for specialists. For instance, the U.S. Foreign Service Institute used the first generation of IFs in a mid-career training program.

The second generation of International Futures was a simplified version written for microcomputer use (specifically the IBM and DOS platform) in 1985. It also targeted educational applications, and CONDUIT again distributed it.

The third generation is a full-scale microcomputer model, first available in 1993. The third edition improved demographic, economic, and other representations, but also added new environmental and sociopolitical content. It drew upon the collaboration of the author with the developers of the GLOBUS model (especially the economic module), created with the inspiration of Karl Deutsch and under the leadership of Stuart Bremer (1987) at the Wissenschaftszentrum in Berlin.

Three editions in the third and current generation have accompanied a book also called *International Futures* (Hughes, 1999). The second edition converted the model to Visual Basic and introduced a much improved menu-driven interface, running under Windows. That release is also available for the MacIntosh (www.tarkvara.org). This article focuses, however, on the third edition or release of IFs in the current generation of the model (www.du.edu/~bhughes/ifs.html). Figure 1 shows the introductory or splash screen from the current generation.

In addition to the student version of IFs, meant primarily for educational use, IFs is available in a professional edition. The primary additional feature of the professional edition is the ability to draw upon the database for 162 countries to restructure the world geographically (through an automated process), according to the needs of the analyst. For instance, the professional edition allows focus on Bulgaria, in the context of other individual Balkan countries, all in a global setting.

Basic Structure and Use of IFs

IFs has the following six modules: demographic, agriculture, energy, economics, politics, and environment.

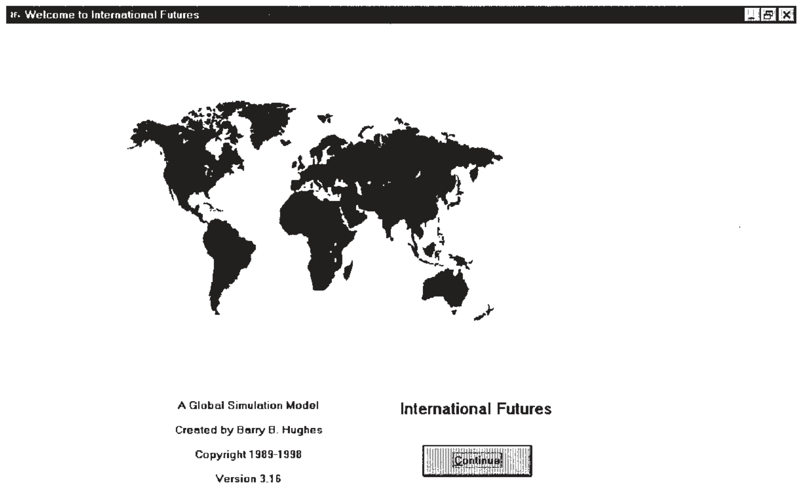

FIGURE 1: Introductory Screen for International Futures (Ifs)

1. The population model of IFs represents 19 cohorts: infants, 5-year intervals up to age 85, and those aged 86 and above. Overall fertility and mortality rates change in response to income, income distribution, and multipliers. The module computes average life expectancy at birth and literacy rate, and it calculates an overall measure of the physical quality of life.
2. The agricultural model of IFs represents production, consumption, and trade of crops and meat. It shows ocean fish catch and aquaculture in less detail. It bases production on land in crop, grazing, forest, urban, and "other" categories. It calculates demand for food, livestock feed, and industrial use of agricultural products. In this partial equilibrium model, food stocks buffer imbalances between production and consumption and determine price changes.
3. The energy module portrays production of six energy types: oil, gas, coal, nuclear, hydroelectric, and other renewable (e.g., photovoltaic, biomass, and wood). IFs forecasts consumption and trade of energy in the aggregate. It represents known reserves and ultimate resources of the fossil fuels and capital costs of each energy form. Energy stocks buffer imbalances between production and consumption and prices change in pursuit of sectoral equilibrium.
4. The economic module simulates the economy in five sectors: agriculture, materials, energy, industry, and services. It is a general equilibrium model that does not assume exact equilibrium will exist in any given year; instead, the model chases equilibrium over time. The economic module encompasses the partial equilibrium analyses from the agriculture and energy modules. International trade uses the pooled rather than the bilateral trade approach.
5. The sociopolitical module has three primary components. Within countries or geographic groupings, the module represents fiscal policy–taxing and governmental spending. The spending categories are military, health, education, foreign aid, and a residual category. Between countries or groupings of countries,

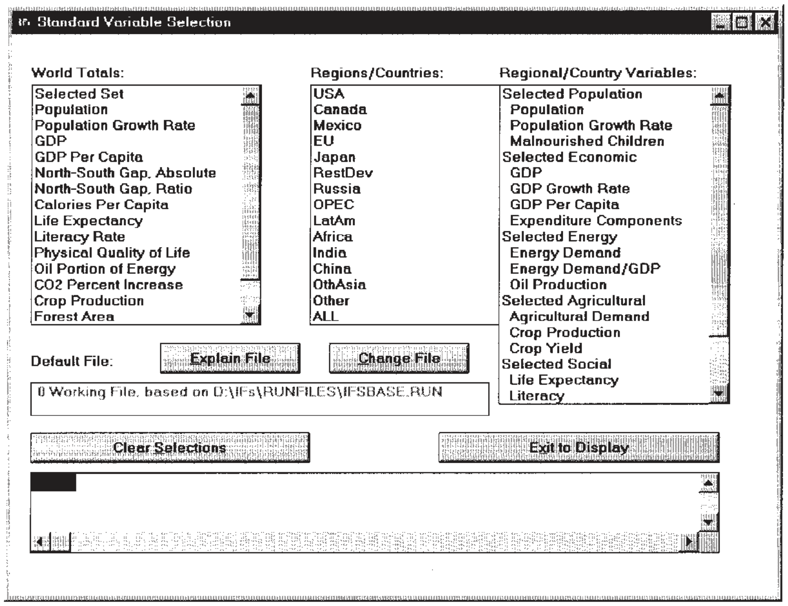

FIGURE 2: Output Variable Selection in International Futures (Ifs)

the module allows the user to explore action-reaction processes of mutual threat, possibly spilling over into arms races with the potential for conflict among countries. Across countries, the model represents social change that typically occurs with development, including increasing democratization and greater equality for women.

6. There is also an implicit environmental module distributed throughout the overall model. It is possible, for example, to track the level of atmospheric carbon dioxide, the area of forested land, the use of fresh water, and the remaining reserves of fossil fuels.

Figure 2 shows a screen from IFs that allows the analyst to select a wide range of basic variables from IFs to display. An extended display screen (not shown) allows selection for display of all initial conditions, parameters, and computed variables. Display options obviously include tables and standard graphical formats, but also include display on a world map.

There are various policy handles scattered throughout all modules for scenario analysis. For instance, in the demographic module, the analyst can hypothesize alternative fertility rates (a government might affect those rates through programs of family planning). In the agricultural module, the user can alter land use patterns (a government could change those through tax

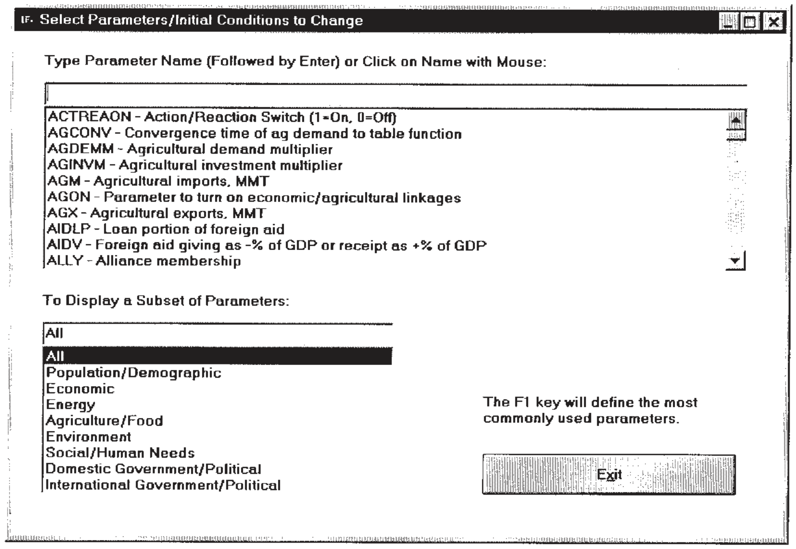

FIGURE 3: Parameter Change in International Futures (IFs)

incentives, zoning, or direct regulation). In the energy module, one can assume different capital costs in the use or production of energy (again affected by tax incentives or legislation). An analyst invokes these policy handles by changing any of more than 70 key parameters. Figure 3 shows a screen that facilitates change of parameters or initial conditions (a total of 327).

In addition to changing individual parameters (using either time-invariant or time-specific values), it is possible to change more than 20 functional relationships within IFs by specifying analytic functions of choice. The IFs system provides help for the development of such analytic functions. For instance, it is possible to create longitudinal or cross-sectional relationships across the extensive, 162-country database and feed those relationships directly to Microsoft Excel for analysis.

IFs is a living model and regularly outgrows documentation. The context-sensitive Help system of the model is the most accurate and up-to-date documentation for the model. The Help system includes step-by-step lessons for all major activities (displaying variables, creating a scenario, running the model, cross-sectional data analysis, etc.). It also provides information on

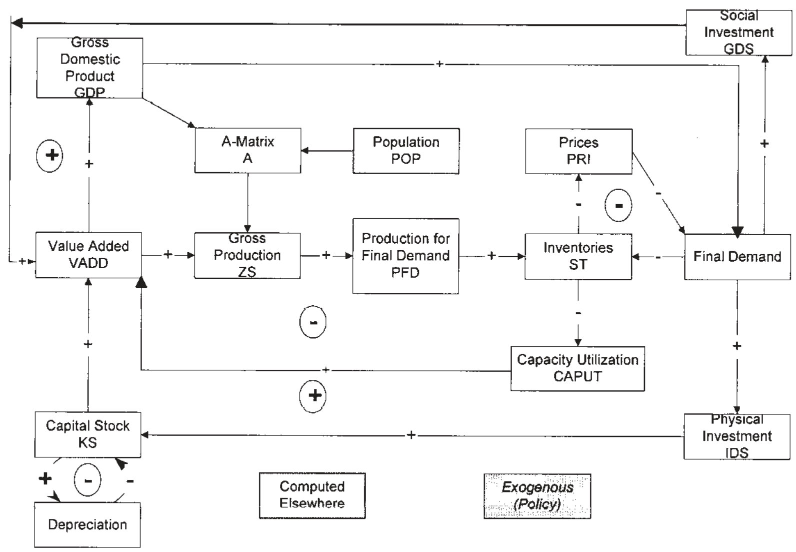

FIGURE 4: Sample Causal Diagram in International Futures (IFs): Economic Module

data sources, other modeling projects, and comparative forecasts. Considerable effort has been made to open up the black box of the model. Therefore, the Help system also includes causal-loop diagrams and equations. See Figure 4 for an illustration of a causal diagram from the Help system. Those interested in the detailed documentation of the Help system can turn to either the model itself or to the IFs web site (www.du.edu/~bhughes/ifs.html).

Using IFs to Analyze Sustainable Development

The motivation behind development of IFs was the need to analyze long-term global change and human leverage with respect to that change. In particular, two issues drove the development of IFs: (a) the importance of global movement toward sustainable development, and (b) the rapidity of country-specific and global sociopolitical change and the great variations in that change across countries. We begin with the issue of sustainability, but will return to sociopolitical change.

Most global forecasting adopts either apocalyptic or millennial character around the issue of sustainability. The Club of Rome's Donella and Dennis

Meadows (Meadows et al., 1972) told us that we faced imminent *Limits to Growth*, and argued more recently that we have, in fact, moved *Beyond the Limits* of sustainability (Meadows, Meadows, & Randers, 1992). In dramatic counterpoint, Herman Kahn forecast that *The Next 200 Years* will be ones of overcoming limits (Kahn, Brown, & Martel, 1976), not being overcome by them thanks to the help of the *Ultimate Resource*, namely people (Simon, 1981). And Ronald Bailey tells us that *The True State of the Planet* (Bailey, 1995) stands in almost complete contrast to the pessimistic vision of Lester Brown's *State of the World* (Brown et al., 1998).

There is important logic behind each of the two modes of futurism, specifically the functioning of feedback loops in reinforcing processes. Environmental and political problems can weaken the capacity of societies to adapt, thereby accelerating declines into collapses. In contrast, technological success buttresses the ability of societies to overcome adversity, potentially transforming individual breakthroughs into periods of sustained growth. Thus, civilizations historically have exhibited broad periods of growth and material progress, as well as marked episodes of decay and collapse.

IFs helps us look down the road into the future from both perspectives. First, we can examine trends in population and economics that give us an aggregate perspective on long-term human development. Second, we can shift our perspective to more specific processes occurring at a more physical level, including the specifics of agricultural, food, and environmental systems. It is apparent that many of those who have looked at human development with the first perspective are quite optimistic about the future, whereas those who adopt the second perspective are more skeptical. The ability of IFs to use and integrate both perspectives is one of the model's strengths.

The base case of the IFs model produced all of the figures shown here, although we used Excel to polish them for presentation. For an earlier version of this discussion of sustainability, see Hughes (1997).

Aggregate Demographic and Economic Transformations

Population. In the 20th century, world population has grown from 1.6 billion people to about 6 billion, with growth rates that accelerated from 0.5% in 1900 to more than 2.0% in the early 1960s. At that time, global demographics passed a critically important but surprisingly little-celebrated turning point: Global population growth rates began to fall. They have fallen to 1.4% as total fertility rates continue a dramatic decline that has taken them from five children per woman globally in the early 1950s to just under three children today.

Global demography recently passed a second critical turning point. Even as global population growth rates fell in the last three decades, the number of

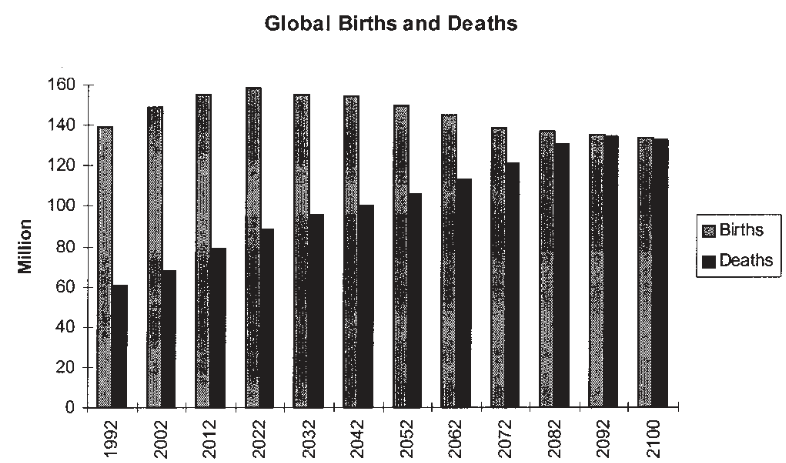

FIGURE 5: Global Births and Deaths Through 2100

people added to the global total continued to grow, approaching 90 million annually early in the 1990s. The annual increment has now fallen to just over 80 million annually (about the population of Germany). Early in the 21st century, as birth rates continue to fall and as deaths in an aging global population continue to rise, the increment will begin to decrease much more sharply (see the forecasts from the base case in Figure 5). We will likely reach a third critical milestone in the second decade of the next century—total global births will begin to decline, even as the world's population ages and deaths continue to rise.

Our level of confidence in such forecasts can be moderately high because fertility and mortality rates tend to change relatively slowly and quite steadily, imparting considerable momentum to demographic trends. Although it is much less certain, many forecasters, including those of the United Nations and the World Bank, anticipate still another global demographic milestone before the end of the next century, namely the attainment of zero population growth. Most commonly, forecasters anticipate a global population of around 10 billion at that time, but low-end forecasts fall below 8 billion.

The forecast of births and deaths in Figure 5, which would lead to a stable world population of about 10 billion people, is, of course, only the base case forecast in IFs. It is important never to treat the base case as a prediction, and IFs therefore allows the creation of alternative scenarios around it. The user can directly alter assumptions about fertility rates and life expectancy. In addition, the user can alter variables that affect the key determinants of mortality and fertility. For instance, it is possible to introduce a multiplier on contraception use. And, of course, changes in any other submodel of IFs (such as economics or agriculture) will have implications for the population scenario.

Economics. The other aggregate transformation of the 21st century will be in economics. In the 20th century, the global Gross Domestic Product (GDP) has grown from about $2 trillion to nearly $30 trillion (each in 1990 dollars), an annual average growth rate of about 2.7% (Maddison, 1995). In per capita terms, global GDP has grown from a bit over $1,000 to more than $5,000. To put this century's change in perspective, consider that the value for $1,500 has been estimated at $565 and that as late as 1820 the global GDP per capita was only about $650. In spite of the Great Depression and in the absence of much growth in most of Africa, the 20th century has seen by far the most rapid economic development in history.

The economic change of the last century has been, of course, extremely uneven. Income inequalities among and within countries have increased markedly. In 1900, the richest countries of the global economy, such as the United Kingdom, the United States, Australia, and New Zealand, had Gross Domestic Products per capita in the $4,000 to $5,000 range (in 1990 dollars), whereas the poorest were at levels below $1,000. At the end of the century the richest have reached per capita levels of around $20,000 and the poorest are still at or below $1,000.

Although few souls are so bold as to forecast global economic growth into (much less through) the 21st century, the prestigious Intergovernmental Panel on Climate Change (IPCC) did just that as a basis for studying the continuing build-up of carbon dioxide. They forecast a 24-fold increase in the global economy between 1990 and 2100 (13-fold in more-developed and 69-fold in less-developed economies, respectively), an acceleration relative to the 15-fold increase of the 20th century. (The IFs base case forecast is comparable.)

Such a forecast might seem outrageous to many who view the slowing growth of the period since the early 1970s (or the crisis of the late 1990s in emerging market economies) to be a precursor to greatly reduced global economic growth. There are, however, good reasons to believe that global economic growth in the 21st century will exceed that of the current century. First, global economic growth has been on a generally accelerating path for more than 200 years. Maddison (1995) pointed out that the period of most rapid economic growth in human history, the Golden Age, was 1950 to 1973.

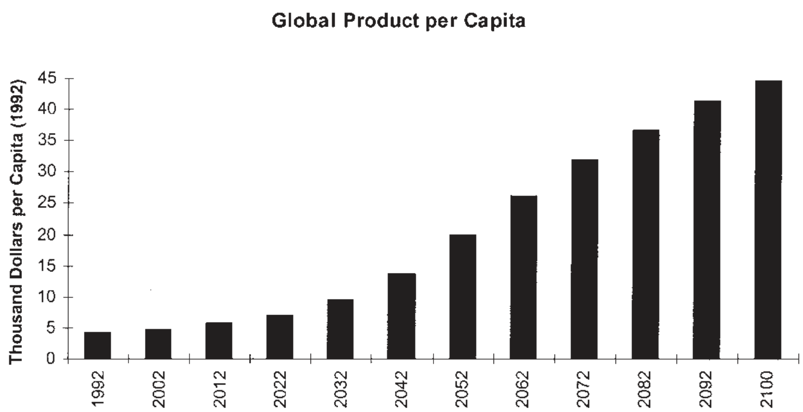

FIGURE 6: Global Product Per Capita Through 2100

Although the second most rapid growth was from 1870 to 1913, the third most rapid was the much maligned 1973 to 1992 period. Second, the very large differentials that have appeared globally in GDP per capita have created the possibility for countries at lower levels of GDP per capita to dramatically increase their growth rates through adoption of existing technology from richer countries. The IPCC forecast is reasonable. In combination with the population forecasts of the IFs base case, it leads to the product per capita patterns of Figure 6.

We need to elaborate the great importance of reaching GDP per capita of $5,000. Dramatic transformations occur in almost all societies as GDP per capita grows from $1,000 to $5,000. Primary school attendance becomes near universal and literacy rises well above 50%. Life expectancy jumps sharply toward that in the richest countries and fertility rates fall very rapidly. Changes in such "quality of life" variables is much less marked above $5,000 per capita than below it. Thus, it is very significant to be able to say that the world on average (although it is a very skewed average) has reached that level. The most dramatic element of economic transformation in the 21st century will be the movement of a large majority of humans above $5,000 per capita. The IFs base case of Figure 6 (again comparable to IPCC forecasts) suggests the possibility of a global average even above levels of developed countries today.

Again, it is critical to emphasize that we have been discussing only the base case of IFs. The modeling system allows a variety of scenario interventions. For instance, assumptions can be changed concerning technological advance in the global system as a whole or by country/region. It is also possible to manipulate multipliers on investment rates, tax rates, export levels, and other economic variables. Furthermore, it is possible to intervene in systems such as energy, agriculture, and the environment that have important indirect linkages to economics. It is to those systems that we turn now.

Food, Energy, and Environment as Rough Patches on the Road to Sustainability

Although our glance at the IFs base case to this point suggests an increasingly stable world demographically and an increasingly rich one economically, things look less comforting when we view the future beneath these aggregates. Will we have enough food for nearly twice as many humans? Will we have enough energy to power our burgeoning economies? In our efforts to feed ourselves and our economies, will we greatly damage our physical and biological environments, thereby undercutting rosy economic forecasts?

Food. Between the early 1960s and 1990s, global per capita calorie consumption increased by about 15%. Levels in less developed countries (LDCs) increased even more rapidly, from 1,990 calories in 1962 to 2,550 in 1992. The population estimated to be malnourished decreased from 900 million (35% of the LDC total) in 1969 to 1971 to 800 million (20% of the LDC population) in 1988 to 1990. Calories consumed globally per person each day rose from 2,440 to 2,720.

In spite of this progress, there is an ongoing debate about our ability to feed ourselves. To put the problem in perspective, an increase in the global population from 6 billion to 10 billion means that we will need to increase global food supplies by a factor of 1.67 just to maintain current dietary levels. To bring global average calorie availability from 2,720 to 3,500, approximately the level in the richest countries today, we would need a further factor of 1.29. To do both, we would seem to need food supply increases of about 2.15 (1.67 times 1.29). However, that would ignore the fact that the increased calories will, if consumers have their preference, come in large part through the addition of more grain-fed meat to diets. Even assuming that we were to eliminate much of the agricultural waste that is prevalent in the food harvesting and distribution systems of LDCs, we need to multiply basic crop production by about 3.5 times to satisfy consumption demand of 10 billion wealthy eaters.

Those, like the United Nations (UN) Food and Agricultural Organization, who look quite optimistically to the future (see the IFs base case in Figure 7)

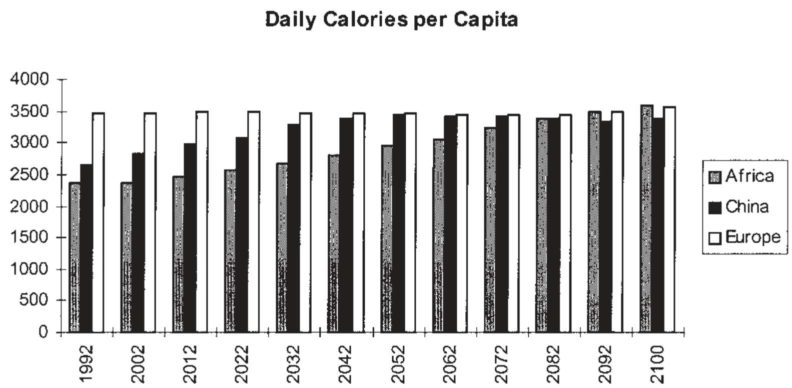

FIGURE 7: Daily Calories Per Capita Through 2100

rely on one major argument: agricultural technology continues to advance, especially as we move into an era of genetic engineering. Moreover, a substantial portion of the world has not yet adopted even current state-of-the-art technology. Remember that global food production more than doubled between 1960 and 1995 (only 35 years), in the face of highly pessimistic forecasts near the beginning of that period.

Those who are anxious about the future of agriculture marshal an impressive array of arguments: agricultural land per capita is declining; land entering production often comes at the expense of tropical forest and has marginal quality; aquifers around the world are being drawn down, and sites for placement of new irrigation reservoirs are dwindling; fertilizer and other chemical use has reached levels that often bring few marginal returns and that contribute greatly to pollution; and ocean fish stocks are falling.

One focal point of the current debate is the prospect for meeting food demand in China. Lester Brown concluded that rapid industrialization will lead to a substantial withdrawal of land from agriculture and a major growth in dependence on food imports (Brown, 1995, 1996). He forecast Chinese imports by 2030 of 300 million to 640 million metric tons of grain. To put that in context, net imports by all of Asia were only about 80 million metric tons in 1990, and North America exported only 110 million metric tons.

IFs allows the creation of a wide range of scenarios around its base case forecast, many of which are much closer to those of Brown (1995, 1996). The analyst can manipulate assumptions about agricultural demand, both in the aggregate and at the level of the portion of calorie needs met by meat. It is also possible to change assumptions about land use and the growth of yield per hectare of land. Similarly, one can introduce alternative assumptions about the ocean fish catch, its division among countries, and the growth of aquaculture.

Energy. The two energy shocks of the 1970s, a decade in which oil prices jumped by a factor of about 10, led many to the mistaken conclusion that fossil fuel shortages were imminent and that a transition to renewable energy was necessary. In fact, known reserves of oil, gas, and coal would satisfy current levels of global demand for 39, 64, and 219 years, respectively. These numbers have all grown since 1973 and there is still considerable potential for reserve expansion.

The real energy issue for at least the first half of the 21st century is environmental impact, not resource availability. Therefore, the important questions for the 21st century are the probable growth in total energy demand and the portion of that which renewable and relatively less-polluting energy forms may provide.

Given the IPCC forecast for 24-fold growth in GDP during the coming century that was reported earlier, what is a reasonable assumption for growth in energy demand? The IPCC itself builds two scenarios, a doubling and a quadrupling of global energy demand. The lower of these scenarios seems incredibly conservative in the face of historic patterns of energy growth (more than 2% annually over a long period). Even in the face of dramatic increases in energy prices and in the context of slowing economic growth, global energy demand grew by nearly 45% between 1973 and 1994. The forecast by authors from the International Energy Agency (IEA; 1995, 1996) and the International Institute of Applied Systems Analysis (IIASA) of a 2.6-fold increase in global energy usage by 2050 appears more nearly reasonable (although probably also low).

Even the 4-fold demand increase at the high end of IPCC forecasts for 2100 seems optimistically low, but IFs adopted something close to it for the base case. How might the world satisfy energy demands of four times or more than those of today? The answer to that question depends primarily on the relative prices of fossil, nuclear, and renewable energy forms. Nuclear energy has actually become more expensive as the full costs of the nuclear fuel cycle, including long-term disposal of nuclear wastes, appropriately become part of costing. Although renewable energy costs continue to fall, those costs remain relatively high, especially in industrial and transportation applications. Fossil fuels remain relatively plentiful and therefore not particularly expensive. Wonderful declarations in Rio and elsewhere aside, there is an extreme global scarcity of political will to tax and discourage fossil fuel use.

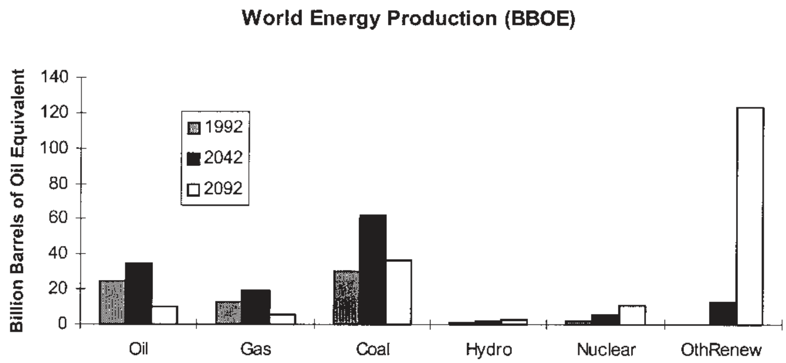

FIGURE 8: World Energy Production Through the 21st Century
NOTE: OthRenew = other renewables.

Leaving aside the contributions that wood and hydroelectric power make, what contributions might other solar or new renewable forms make in the first half of the next century? The World Energy Council (WEC; 1993) suggested that the new renewables are unlikely to provide more than 5% to 10% of global energy by 2025, and the IPCC, which sought to develop low-carbon scenarios, is barely more optimistic. Only after the middle of the next century are renewables likely to make large contributions (see the base forecasts of IFs in Figure 8).

IFs once again includes many parameters or policy handles for introducing alternative assumptions. It is possible to directly manipulate assumptions of energy demand, as well as to change assumptions about its elasticity with price and income. The analyst can even introduce assumptions about carbon taxes in dollars per ton of carbon emissions. On the supply side, an analyst can use multipliers to change patterns of production directly, but can also intervene via alternative assumptions about investment levels, capital costs of various energy forms, and fossil fuel resources.

Environment. To repeat, the real issue for the future of energy is not resources, but environmental impact. Although much of that adverse environmental impact will be local, the issues about which we must worry most have a larger scale. Of those, the most troublesome is the build-up of atmospheric carbon dioxide (CO_2) and consequent global warming.

It may seem cavalier to skip over deforestation here. In fact, IFs does represent the process and the base case suggests that we are likely to lose at least another 10% of global forest area in the next century. Similarly, there is

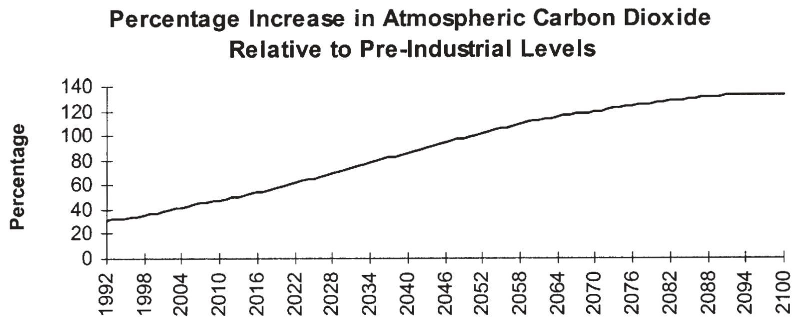

FIGURE 9: Increase in Atmospheric Carbon Dioxide Through 2100

increasing recognition of the problems associated with unsustainable use of fresh water (again, IFs allows some analysis of the issue). Nonetheless, global warming is likely to be the most substantial global environmental problem.

Little debate continues around the reality of CO_2 increases or of attendant global warming and increases in sea level. Atmospheric CO_2 was 280 parts per million by volume (ppmv) prior to global industrialization and is about 350 ppmv today. The IPCC, drawing on the collective research and insight of hundreds of scientists around the world, tells us that even if were we able to hold emissions to current levels through the end of the next century, atmospheric CO_2 would rise to about 500 ppmv.

Such a presumption of constant emissions would not be a reasonable forecast. The medium forecast of the IPCC, using very conservative energy forecasts, was that atmospheric CO_2 will reach 650 ppmv by 2100. Their calculations suggested that this will mean a 2° Centigrade increase in global temperature and about a half-meter rise in ocean level. The IFs base case forecast is comparable. Figure 9 suggests that we will have doubled atmospheric CO_2 (to about 600 ppmv) by 2050 and that it will continue to rise slowly. IFs does forecast resultant temperatures.

IFs provides analysts with considerable capability for scenario development around global climate. For instance, there is considerable uncertainty over future absorption of atmospheric CO_2 by oceanic and other sinks, and IFs includes a parameter to alter assumptions. Most scenario analysis around this issue will, however, focus on the energy system, and scenario analysis with it was discussed earlier. In addition, IFs includes an ability to build scenarios around the feedback affect of atmospheric CO_2 on agricultural systems.

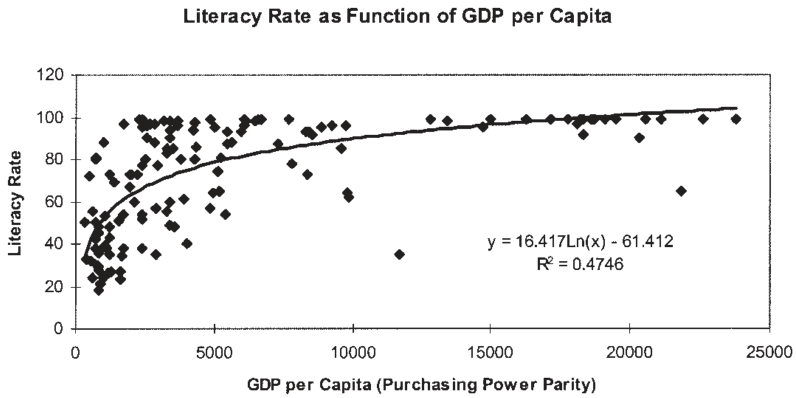

FIGURE 10: Literacy Rate as a Function of Gross Domestic Product (GDP) Per Capita

Using IFs for Analysis of Social and Political Change

The overarching demographic and economic transformations of the next century are likely to be dramatic. The efforts to deal with food sufficiency, energy availability, and environmental quality will be complicated and difficult. Social and political change in the coming century could, however, prove comparably dramatic and complicated. IFs also facilitates forecasting and scenario analysis around sociopolitical change.

Domestic Social Change

We noted earlier the significance of reaching GDP per capita levels of about $5,000. We should amend that somewhat. Much of the most dramatic social change occurs as GDP per capita measured in purchasing power rises toward $5,000, a transition that normally occurs as GDP per capita measured in exchange rates climbs to about $3,000. Because most of the world's population lives in countries with GDP per capita below these levels, a large portion of the social change associated with increased income levels has yet to occur. It is highly probable that, by the end of the 21st century, most of that transition will be complete.

What are the implications of such a forecast? As GDP per capita in purchasing power parity rises to $5,000, life expectancy rises to the high 60s, within a few years of the longevity that those in the richest countries now

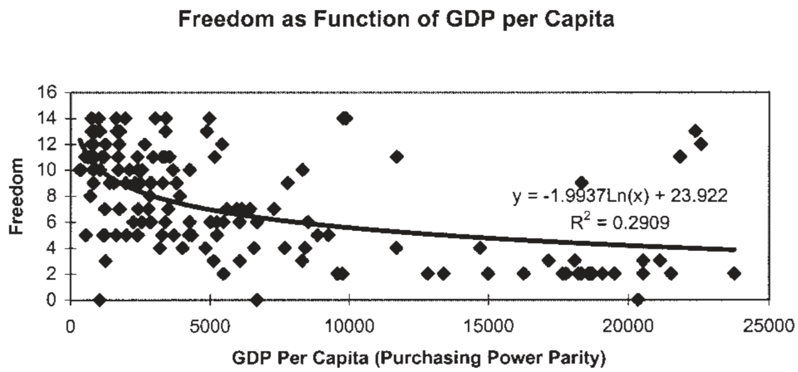

FIGURE 11: Freedom as a Function of Gross Domestic Product (GDP) Per Capita

expect. To put this in context, even with modern medical technology, life expectancy for those in the poorest countries is currently in the mid-40s. Similarly, in transition to $5,000 per capita (purchasing power parity [PPP]), the total fertility rate or number of children borne by each woman in a population falls from 6.0 to 7.0 to about 3.0, not far above the 1.5 to 2.0 rates of the richest countries. And literacy rates rise from below 50% to nearly 80%, well along the path toward universal literacy (see Figure 10). These transitions are fundamentally important, and because they have a strong start globally, the 21st century should see their completion in all but isolated geographic pockets.

Moreover, the impact of these social transitions extends beyond individual quality of life to social organization. The Freedom House assesses democracy in countries with two 7-point scales on which lower numbers mean greater democracy. The sum of those scales drops from very high levels to about 7 at $5,000 per capita (PPP), and then drops much more gradually at higher levels of GDP per capita (see Figure 11).

IFs produced Figures 10 and 11 by using the 162-country database that accompanies the modeling system. IFs gives the analyst the capability of creating such a scatterplot between any two data series and then taking the scatterplot directly to Microsoft Excel for the fitting of a curve.

One can go an important step further by bringing many such functions back into IFs. Figure 12 shows the Window that allows introduction of more than 20 such functions via either a table function or an analytic form.

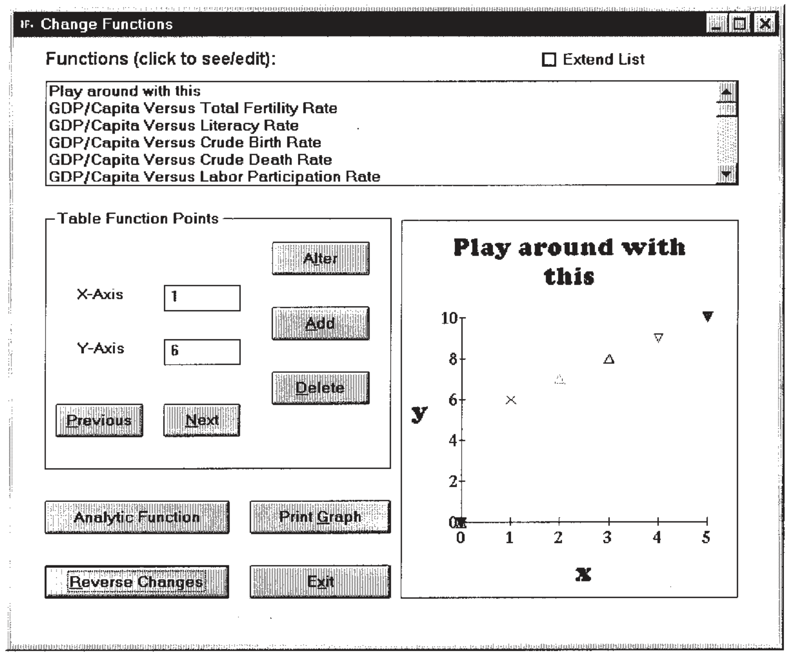

FIGURE 12: **Window for Changing Functional Forms**

Global Political Change

We can anticipate significant social and political change in the next century internal to a wide range of countries. Some internal changes will have external and even global consequences. For instance, there is considerable potential for expansion of the grouping of rich, democratic countries that also boast relative demographic stability and high standards for human rights. To the degree that the linkage between democracy and peace continues to hold, these changes hold out the promise of a larger interstate zone of democratic peace.

It would be foolish, however, to anticipate that the traditional rules of interstate politics will be repealed. Among the most important of those rules is that changes in power position at the top of the interstate power hierarchy hold great danger of conflict. Seldom does the leading state of the system turn over its dominant systemic position without struggle.

The two most significant power transitions of the 21st century will likely involve China. First, China will climb above Japan in power. That will occur very early in the century. Already China is reaching the level of Japan in terms

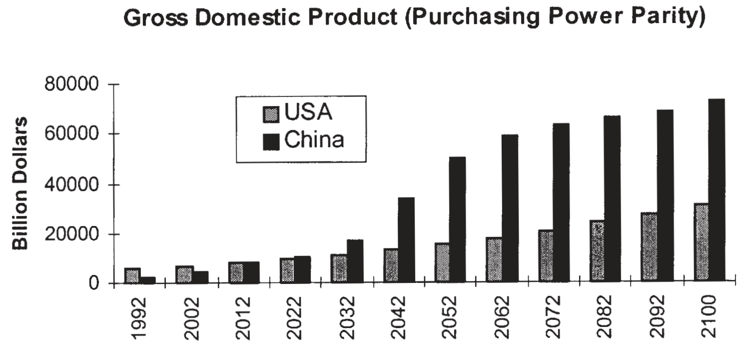

FIGURE 13: The Transition of China to Global Economic Leadership

of GDP at PPP. Given current growth rate differentials, it could surpass the GDP of Japan in exchange rate terms before 2020. It is also likely to attain conventional military power parity with Japan between now and 2020 and already has a nuclear capability that the Japanese have forsworn.

The second transition will be China's overtaking of the United States itself. If China were to maintain economic growth rates of 10% each year (which is highly improbable) and the United States continued to struggle for rates of only 3% annually, Chinese overtaking of the United States would follow its passing of Japan by only about 10 years. Even if Chinese economic growth falls to 7% to 8% annually, both power transitions are probable before the middle of the next century.

Interestingly, in 1820 China and India had by far the largest GDPs in the world, although they lacked significant internal coherence and external strength. China's GDP was more than five times larger than those of France or the United Kingdom (Maddison, 1995, p. 30). By 2100, China's GDP will probably be more than twice the size of the United States (see Figure 13), and again more than five times the GDP of either France or Great Britain.

As always, we should not take this base case forecast too seriously, however intriguing it might be. Practically all of the scenario options discussed to this point allow changes in assumptions that might influence this power transition.

Anticipated Development Directions for IFs

World modeling, the development of computer simulations to investigate the interrelated dynamics of multiple global systems, is not quite 30 years old. It remains a field very much in its youth. IFs has grown with the field, incorporating as much as possible from other efforts within it and attempting to make the accumulated knowledge of world modeling widely available. That will continue to be the goal of the IFs' project through the next decade.

The primary substantive foci of IFs will remain relatively constant, around the themes of transition to sustainable development and extensive global social transformation. This article has sketched the general capability of IFs to explore these themes, but analysis of each will become increasingly more detailed. Model extensions will continue to support such analysis. For instance, it will be useful to elaborate the demand-side of the energy model by sector (household, transportation, etc.). It will also be useful to extend the representation of social change, and in particular to model systemic shifts over time in the cross-sectional relationships that we see today. Addition of immigration will improve demographic modeling. Better representation of capital flows will improve economic modeling.

Another very important area of development will be the linkage of the model to more extensive historic, country-specific data. This may be done either by adding such data to the already substantial data files that accompany the third edition of the current generation, or by online linkage to databases of research institutions.

The user interface of IFs will also continue to improve. Changes in the file handling, in linkage to other applications, and in simplified scenario introduction will all improve IFs. Important changes in the user interface will be the placement of all menu text into files so that translation of the interface into other languages is relatively straightforward.

The most challenging area for model development will, however, be interface with the knowledge gained by other modeling projects. By opening up its black box as much as possible, IFs attempts to contribute to the crossfertilization of the field. One development option that will be very important to explore in coming years will be open, online modeling. That is, it is already possible to place world models online via the Web, and a version of IFs will be online. The next logical step may be to create an open model, one into which components of other models could be swapped. For instance, it would be ideal if a library of demographic or energy models could be available for users and selected on demand. Because of the necessity for careful specification of interface requirements, that will not be an easy step.

Finally, educational applications and analysis with IFs should continue to grow. With respect to classroom use, Johnson and Boyer (1994), Boyer and Johnson (1995), and Borock (1996) have explored the capabilities of IFs. With respect to future research and analysis, Krupa, Kickert, and Jäger (1998) and Glenn and Gordon (1998) have done the same. Constructive critics are friends, and the author welcomes use of IFs and suggestions for its improvement.

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