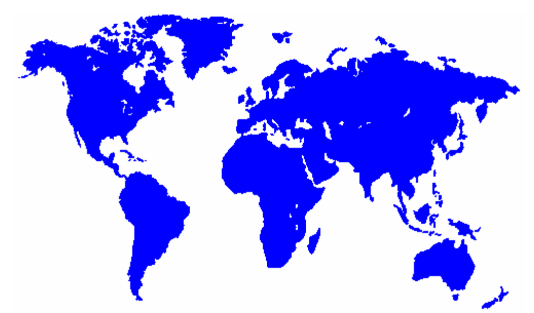

Assessing the Credibility of Forecasts Using International Futures (IFs):

Verification and Validation

Barry B. Hughes

The work reported in this paper would not have been possible without the computer system development skills of José Roberto Solórzano Arévalo. Over a period of several years he has put in place, among much else, the interface capabilities for historical analysis of IFs against empirical data and for presentation of forecasts as an extension of historical series.

Version 1.0. Feedback on this living document will be much appreciated.

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Table of Contents

Abstract

No model of complex human systems can ever be "validated," but some produce more credible forecasts than others. This paper describes the approaches that have been taken toward assessing the credibility of the International Futures (IFs) modeling system and the results of those efforts. It discusses the various notions of validation and related concepts and then explores structural validation, behavioral validation against historical data, and behavioral validation with respect to forecasts and applications. Validation of a complex model is never achieved, but credibility can accrue with ongoing efforts.

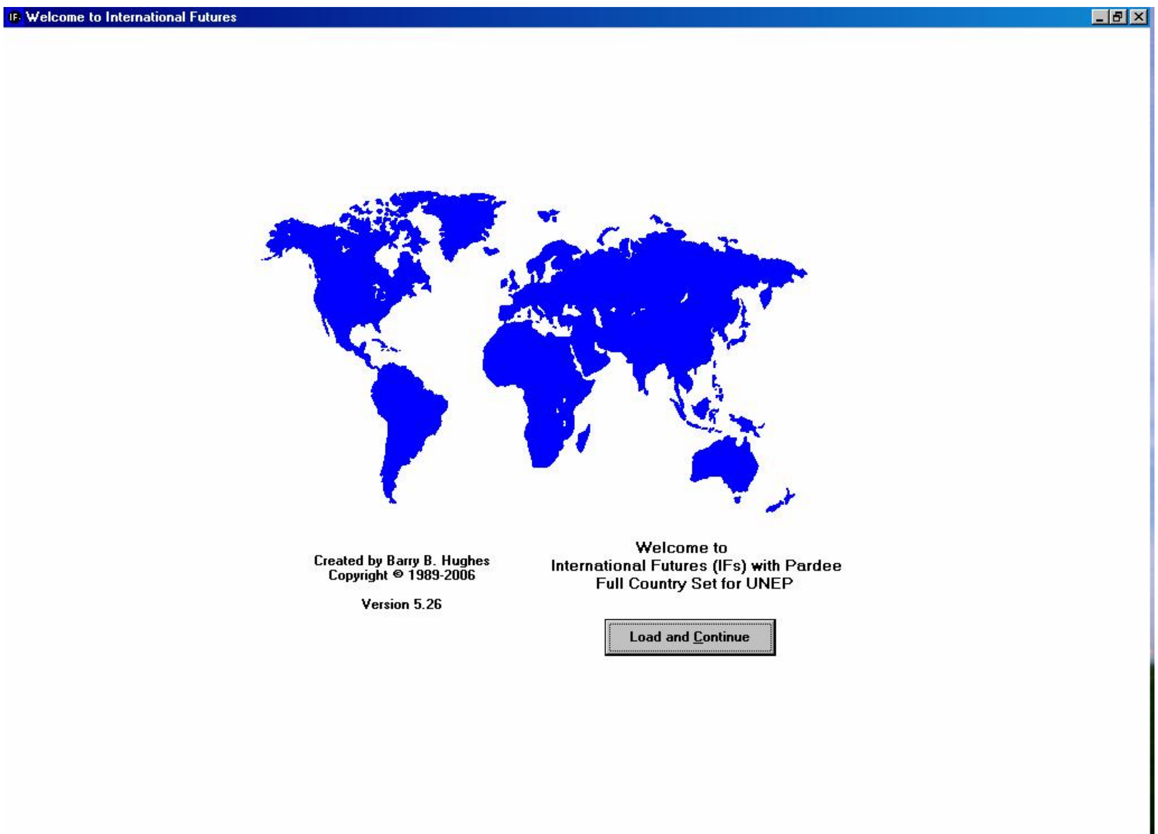


Figure 1. Welcome to IFs.

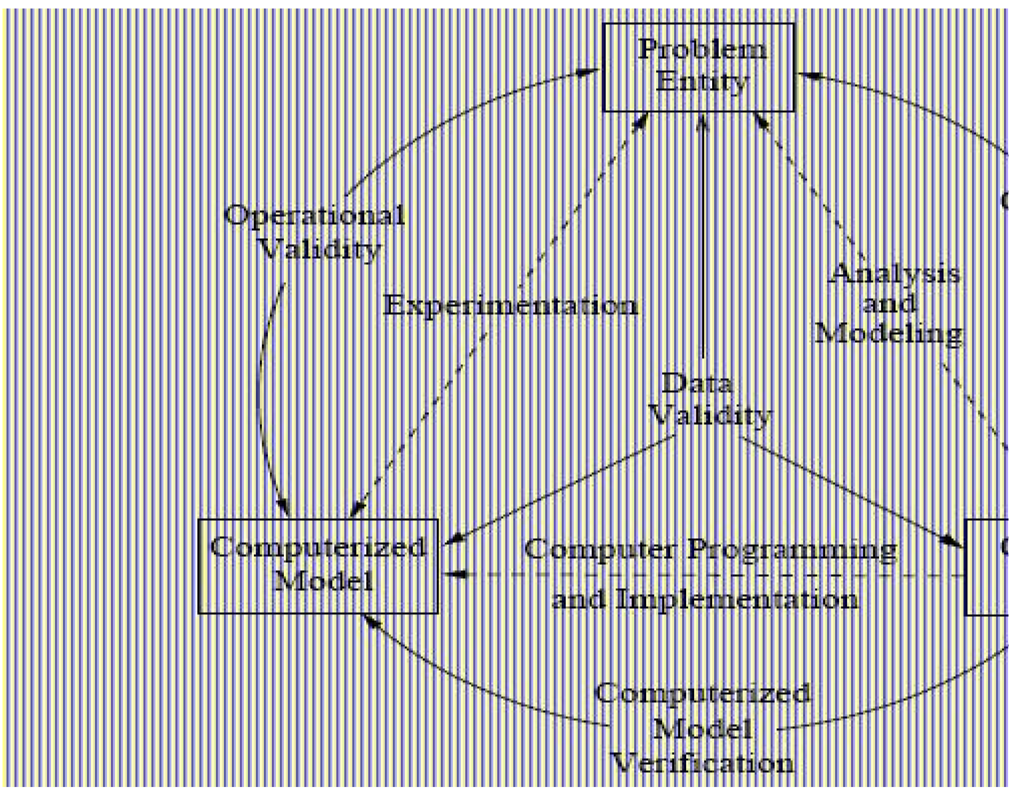
Funding for this paper was provided by the Office of Transnational Issues of the U.S. Directorate of National Intelligence and special appreciation is due to Jeffrey Staats and John Sullivan.

1. Verification, Validation, Accreditation

The purpose of this paper is to discuss the credibility of forecasts made with the International Futures (IFs) simulation. It is common to talk about validating computer simulations. When the simulation is of a complex social system, however, validation is essentially impossible. The many reasons it is impossible include the ironic one that a particularly strong model might itself influence human behavior – prophecies can be self-denying. More generally analysts focus on what is known as Verification, Validation, and Accreditation (VVA) of models and their forecasts. There is an extensive literature on the concepts and the approaches for VVA. Among others, see Forrester and Senge (1980), Hodges and Dewar (1992), Barlas (1996), Arthur and Nance (1997), Sargent (1998, 2000), Roy and Mohapatra (2003), Allen, Shaffer, and Watson (2005), Qudrat-Ullah (2005), and Macal (2005).

Validation-Related Concepts

The trilogy of VVA concepts has come to be accepted when thinking about the usefulness of models (see Arthur and Nance 1997; Sargent 2000). The figure below from Sargent conveya the content of the verification and validity concepts.



Source: Sargent (2000: 52).

Verification "ensures that the computer programming and implementation of the conceptual model are correct" (Sargent 1998: 125). In many respects this is the easier of the verification and validation tasks because it accepts the conceptual model as is. Yet it is far from easy because the translation of rich conceptual models into large-scale computer simulations inevitably does some violence to those models, and computer programming almost invariably introduces bugs that can be undiscovered for months or years.

What Sargent calls conceptual model validity in the figure above, others sometimes call structural validity. Similarly, what he terms operational validity is sometimes labeled behavioral validity (Quadrat-Ullah 2005). Whatever the terminology, the distinction between the two forms of validity is fairly obvious, and both concepts are important. Non-modelers sometimes assume that a model is valid if it reproduces history. Modelers know that analytic forms can be found that fit essentially any historic series. Such forms do not necessarily provide a valid model for reasons related to both validity concepts. First, they do not capture the structure of the system being modeled. For instance, a sophisticated time-series model of Chinese population growth over the last few decades that did not somehow conceptualize and represent the changes in fertility wrought by political decisions to push two-child and then one-child families might have beautiful historic fit but tell us nothing of real interest about either the Chinese historic patterns or those of other countries, past and future. Second and related, such forms would not allow us any points of intervention or experimentation. We could never ask and address questions such as what would might happen if the one-child policy were abandoned.

It is widely accepted that validity is directly related to the purpose of the model and the purposes of any really useful model go beyond simply reproducing history into (a) helping us understand the character and/or dynamics of the system represented and (b) helping us understand its behavior with interventions (such as possible policy choices).

It is also generally accepted that models of complex systems are never really validated. Instead, in the terminology of Hodges and Dewar (1992: vi) models “accrue” validity “along a continuum between ‘not valid’ and ‘valid’.”

That accrual of validity brings us to the notion of accreditation. Sargent (2002: 57) quotes a Department of Defense’s definition of accreditation as “the official certification that a model or simulation is acceptable for use for a specific application.” Note how this definition again ties the concept back to a particular application or purpose.

In the case of the International Futures model, there is no single client or other agent of accreditation. There are instead a large number of users, as will be discussed later. In this paper we therefore refer not to accreditation in the traditional sense, but instead to the larger credibility of the forecasting tool.

The next chapter overviews specific approaches to the validation and verification effort, tying those specifically to the purposes of International Futures (IFs) and the processes of its development. Chapters 3-6 turn to the details of the efforts to assess the credibility of IFs and its forecasts.

2. Evaluating IFs

Models are simplifications of systems developed for specific purposes. Validation and verification depend on the target system and the purposes for the model. Therefore this chapter begins by identifying those. It then proceeds to lay out the nature of the efforts that have been undertaken to evaluate IFs.

2.1 The Target System: International Futures

International Futures (IFs) is a large-scale integrated global modeling system.[1] The broad purpose of the International Futures (IFs) modeling system is to serve as a thinking tool for the analysis of near through long-term country-specific, regional, and global futures across multiple, interacting issue areas.

IFs allows variable time horizons from a 2000 base year for exploring human leverage with respect to pursuit of key goals in the face of great uncertainty. Three sets of values and goals with which few would disagree increasingly frame global initiatives and the structure of IFs (see the table below). First, humans as individuals should be able to develop their capabilities as fully as possible, attaining literacy, securing nutrition and health care that allow a reasonable life expectancy, and gaining access to a basic level of economic resources. The broader purposes of these capabilities are to allow individuals substantial freedom of choice in their pursuit of a fulfilling life (Sen 2000). Second, humans in their interactions with one another desire peace and security (Kant 1795) and also basic fairness and justice (Rawls 1971). Third, humans in their interactions with a broader biological and physical environment should be able to live in a sustainable manner so that life styles and choices do not jeopardize the life conditions of their own futures and those of subsequent generations (United Nations/Brundtland Commission 1987). Collectively, these goals have increasingly come to be recognized as the pillars of "sustainable human development," the overarching or "meta-goal" of most who think about and act to enhance global futures.

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[1] Current funding for IFs comes from Frederick S. Pardee, the U.S. National Intelligence Center, and the United Nations Environment Programme. Funding for this paper was provided by the Office of Transnational Issues of the U.S. Directorate of National Intelligence; special appreciation is due to Jeffrey Staats and John Sullivan. Recent developments to International Futures have been funded in substantial part by the TERRA project of the European Commission, by the Strategic Assessments Group of the U.S. Central Intelligence Agency, by the RAND Frederick S. Pardee Center for Longer Range Global Policy and the Future of the Human Condition, and by UNEP. In addition, the European Union Center at the University of Michigan provided support for enhancing the user interface and ease of use of the IFs system. None of these institutions bears any responsibility for the analysis presented here, but their support has been greatly appreciated. Thanks also to the National Science Foundation, the Cleveland Foundation, the Exxon Education Foundation, the Kettering Family Foundation, the Pacific Cultural Foundation, the United States Institute of Peace, and General Motors for funding that contributed to earlier generations of IFs. Also of great importance, IFs owes much to the large number of students, instructors, and analysts who have used the system over many years and provided much appreciated advice for enhancement (the Help system identifies some). The project also owes great appreciation to Anwar Hossain, Mohammod Irfan, and José Solórzano for data, modeling, and programming support within the most recent model generation, as well as to earlier direct participants in the project (see again the Help system).

Humans as Individuals	Human Development/Freedom
Humans with each Other	Security/Social Fairness
Humans with the Environment	Sustainable Material Well-Being

This paper does not document IFs. For detail on the International Futures system see the IFs website at www.ifs.du.edu. That site provides the web version of the full model, as well as a full downloadable version for use on Windows machines. The most important source of documentation for the model is its extensive Help system, available with both web-based and downloadable versions. The Help system includes assistance with the user interface, and also includes flow charts, equations, and computer code for all substantive sections of the model. Hughes and Hillebrand (2006) provide a basic introduction to the model with a focus on facilitating its use by the reader. In addition a substantial set of project reports and working papers sit on the web site at http://www.du.edu/~bhughes/ifswelcome.html. Those of particular interest for readers of this paper may be:

Hughes, Barry B. with Anwar Hossain and Mohammod T. Irfan. 2004 (May). "The Structure of IFs."

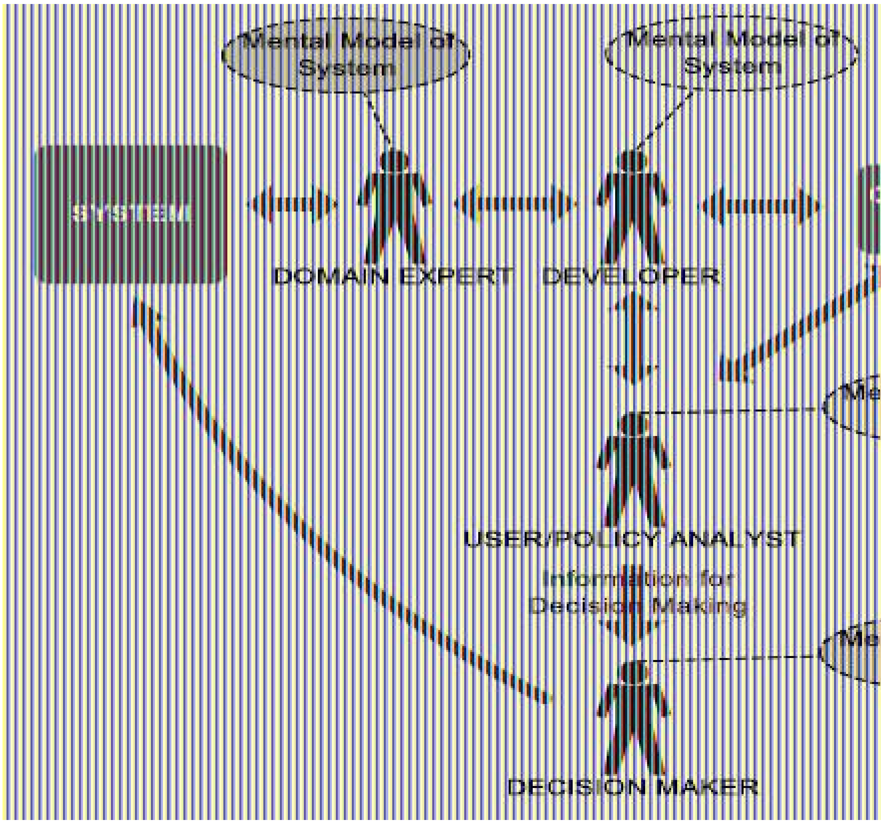
Hughes, Barry B. 2004 (March). "The Base Case of IFs: Comparison with Other Forecasts."

Hughes, Barry B. 2004 (July). "Scenario Analysis with International Futures (IFs)."

2.2 Validation and Verification as a Process, Not an Event

The development of the International Futures (IFs) system as a thinking tool has been proceeding over three decades. Therefore validation and verification efforts have also been ongoing rather than having the character of an event prior to the use of the model.

During that entire period there have been users who have very much been part of the process of model development, validation, and verification. The figure below by Charles Macal shows how quite different individuals in a model development and use process contribute their mental models of the reference system to the development or use and therefore the assessment of the system. The development of IFs has not generally drawn upon domain experts as development partners, but the understandings of those who contribute to the large and varied literatures on which it draws have been, in essence, part of the process. Similarly, there have generally not been decision-makers around global issues directly involved in the use of IFs, but it has increasingly become one of the highly varied sources of information that are available to them. Many of the users of the model have been students and their professors, but increasingly they have been those in policy analysis positions as well.



Source: Charles M. Macal. 2005 (April 7-9). Model Verification and Validation, presentation at Workshop on Threat Anticipation: Social Science Methods and Models, University of Chicago and Argonne National Laboratory, Chicago, Illinois. Available at http://jtac.uchicago.edu/conferences/05/resources/V&V_macal_pres.pdf (May, 2006).

It is useful to think of most of the efforts at validation and verification as falling into two general categories: (1) documentation and inspection and (2) testing and analysis. Documentation and inspection make possible transparency – the possibility for model users, and even of the developers themselves, to see and understand what is in the model and to compare the model with the system being modeled. Testing and analysis illuminate the behavior of the model, again making possible the comparison of it with the reference system. The table below shows some of the elements in the two categories.

	Conceptual Validation	Operational Validation	Functional Verification
Documentation and Inspection			
Diagrams (block, causal)			
Equations			
Computer Code			
Data and Parameters			
Testing and Analysis			
Historic Calibration			
Forecasting Use			
Interventions			

The rest of this chapter provides more information on these processes in general terms and subsequent chapters elaborate them.

2.3 Documentation and Inspection

The representation of a real world system as a computer simulation involves, as the Macal diagram made so clear, the formalization of mental models of the real world system. That formalization normally has several steps.

The first is the representation of the system via block diagrams (what are the key components?), causal diagrams (what are the key linkages among system elements?), and/or systems dynamics representation (what are the stocks and flows, where are the boundaries?). Such diagrams help those with extensive domain knowledge in particular to see whether the model has been inclusive while remaining sufficiently parsimonious, to judge its treatment of accounting identities as appropriate, to evaluate its causal representations, and to gauge its likely dynamics.

The second step is formalization of the model into equations. Equations add specificity with respect to functional form of relationships. Because experts have often worked to formalize many systems over long periods of time, the equations allow them to compare and contrast models in terms of what are often alternative formalizations of the same system.

The third step is rendering of the equations into usable computer code. This step is sometimes misunderstood as a simple translation exercise, but it is considerably more. It requires precise specification of equations that might be stylized in presentation, the addition of initial conditions and parameters that might be shown in equations only via notation, and the complete rendering of dynamic elements such as solution sequencing and iterative processes.

Ideally there should be many eyes on the stages of this process: the domain experts, the model developers, and the model users should all be involved. Black boxes cannot be validated or verified. Thus extensive, careful documentation is essential. Among the eyes that help review it should be the developers (with repetitive review and revision), peer reviewers of published documentation, and various users.

2.4 Testing and Analysis

Testing and analysis has many elements. The first and one of the very most important is often production of results that past the "smell test" or have face validity. Results must also be free of transients or other unintelligible behavior. Analysts, particularly those using models with complex feedback systems, are often interested in obtaining "non-intuitive findings." The sad reality is that most such findings are simply bugs and their elimination is part of the verification process. All of the rest must become intelligible or intuitive to the model developers or users. Thus non-intuitive results should disappear, except for their use to enrich the mental models of those inside and outside of the development process.

A second element of testing and analysis is often the much-vaunted *historical validation*. As indicated already in chapter 1, this is an important step, often as much for accreditation as for validation, but it is also misnamed because it cannot really validate a model of complex social systems. Those systems are never exactly the same in the future as in the past. Moreover, we often lack the quality of data we would need for really strong historical testing. More accurately, the process is one of *historical calibration,* in which the model results are examined against the data that are available and judged to either reproduce them adequately or to be understood as results of understandable differences between the historic and future systems.

Another important element in testing and analysis is repeated use of the model to produce forecasts, producing a record over time that again can be judged to have been reasonably accurate or regularly errant. Because those who use models should seldom simply convey their "model run" results as a forecast, but should take real care to analyze results, adjust/fix the model, and provide context for the findings, the track record becomes in substantial part that of the modeler/forecaster, not just of the model.

Still another element with respect to testing and forecasting is the comparison of results with those of other forecasters. Very often there are other models with somewhat reasonably understood strengths and weaknesses relative to the strengths and weaknesses of the instrument being used. The forecasts produced by those can be a good reference for judging forecasts of a given model, especially for long horizons during which the ability to judge against real-world developments may not be possible.

And yet another element of testing and analysis is studying the behavior of the model in the face of interventions, which might be selected for specific analysis of possible agent behavior or which might be selected as extreme cases of theoretically possible intervention. In both instances, the interventions frequently will represent alternative patterns of agent behavior and often it will be of behavior intended to push the system in a desired direction. Because there will very often be no clear historic reference for analysis of the results of the intervention (at least not one without many compromising, non-equivalent features), and because there will seldom be highly credible alternative models against which to judge the results, the analysis of alternative forecasts relative to the intervention becomes one with considerable subjectivity, demanding as much domain knowledge as possible.

One more systematic approach to examination of interventions is sensitivity analysis, the systematic variation of parameters across a specified range, first singly and then in combination, in order to both better understand the model and as a tool for debugging and enhancing it. There is also the possibility for models to sit inside software shells constructed for the purpose of exercising them extensively and mapping behavior.

When modelers talk about “tuning” their models, adjusting structures and parameters in the face of such interventions is one of the kinds of behavior to which they often refer. Ironically, this kind of modeler-specific content inside the model is most pronounced with respect to precisely the use of the model of greatest importance to those for whom it was developed, that is the impact of alternative interventions. It is one of the reasons that model development and use (at least for social systems) must be considered an art rather than a science, and why results conveyed must be understood to represent the voice of the modeler, not just some completely objective, independent model. (Hodges and Dewar (1992) raise the question “Is It You or Your Model Talking?” and make clear that it must be understood that the modeller is doing much of the talking.)

This chapter has identified some of the elements of and approaches to validation and verification in the pursuit of credibility (or accreditation). The subsequent chapters will focus on the manner in which these approaches have been used within the IFs project.

3. Documentation and Inspection

Writing documentation is not much fun. Yet every modeler understands that all time spent on documentation is productive. The efforts often begin as an effort to enhance communication with others and to facilitate transparency and therefore assessment. They frequently end up being a key aid to self-examination and model review by the modeler herself or himself.

3.1 What is the State of Documentation of IFs?

Although it could certainly be better, IFs is quite fully documented. A significant number of articles and books have been peer-reviewed and published (indicated in this discussion with an asterisk *). Many additional working papers have been developed in the last 5-6 years and are being gradually prepared for publication; most of those are available on the web for examination.

There are multiple elements of the documentation of IFs. First, there are **foundational documents that position IFs** in the modeling and substantive literatures on global futures. Early in the IFs project, Hughes (1980)* reviewed all of the key world models of the 1970s in order to identify their key similarities and differences as a foundation for IFs. Similarly, Hughes (1985a)* surveyed the literature on alternative futures, identifying methods and competing forecasts and analyzing strengths and weaknesses. Hughes (1985b)* positioned the first generation of the IFs model in these literatures, focusing on large world views or paradigms that shape different approaches and models.

Second, throughout the project's history there have been a number of **surveys of the overall status of the modeling project**. These have been published in a number of venues: see Hughes (1988)* in the *Social Science Microcomputer Review*; Hughes (1999)* in *Simulation and Gaming*; Hughes (2001a)* in *Futures*; and Hughes (2002) in *UNESCO Encyclopedia of Life Support Systems (EOLSS).*

The most recent and unpublished surveys can be found on the IFs website. Hughes, Hossain, and Irfan (2004 May) describe "The Structure of IFs." Hughes (2006 February) provides an Introduction to IFs, 3rd revision, which provides information on the history and philosophy behind IFs, as well as a survey of its structure and user interface.

Third, the IFs project is based heavily on a combination of **data analysis and domain investigation**. As part of its effort to strengthen representations in the energy submodel, Hughes (1986)* investigated the oil shocks of the 1970s and their consequences. Similarly, Hughes (2001b)* and (2004)* explored global social change.

Hossain and Hughes (2004 July) provide documentation on the extensive database of IFs. Hughes (2006 May) details the manner in which the data preprocessor of IFs manages the processes of data cleaning and reconciliation in the preparation of the model's data load.

Fourth, the project has always made the model freely available and provided **assistance to users**. In fact, feedback from that use has been quite probably the single most important aid to model verification and validation, because it has mobilized literally thousands of individuals in analysis and testing. Hughes (1993, 1996, and 1999)* provided three generations of a volume helping readers understand the model and its use. Hughes and Hillebrand (2006)* provide the fourth generation of that volume.

Fifth, **extended documentation of the model's structures** is available. All submodules of IFs have been mapped via block diagrams and with equations, and the code of the substantive modules of IFs is fully available for examination. The primary source of all of this is the Help System of the model. That Help System is available with the model. Features of the model's interface facilitates navigation through the help system. These include context-sensitive help with respect to using the interface. Especially important, however, is help when parameters and variables are selected for display or change during the model's use – requests can be made to show definitions, relevant block diagrams, equations, and code. In most cases the presentation of equations is accompanied by discussion that helps the user understand the specifications used in the model and the manner in which different portions of the model are linked.

In addition to the Help system, there are more extended papers on selected aspects of the model. The economic submodule has received special attention because it sits at the interface among demographic, agricultural, energy, environmental, and socio-political modules. The earliest versions of the economic module in IFs were taken into the GLOBUS world modeling project (Bremer 1987) and developed further there before being brought back into IFs. Thus the documentation of the GLOBUS economic model (Bremer 1987; Hughes 1987)* provides considerable insight into that of IFs (although IFs did not bring back from GLOBUS either the labor market representation or the dyadic representation of global trade).

In addition, more recent papers have been prepared that emphasize the relationship between the economic module and a broader Social Accounting Matrix (Hughes and Hossain 2003) and that emphasize the specification of the critical production function, especially its endogenous treatment of multi-factor productivity (Hughes 2005 May #1 and May #2).

Another model that has received particular attention in documentation, in this case because it is newly developed, is that on education. See Irfan (2005).

Sixth and finally, there are a growing number of **works that use IFs in forecasting** projects. These include a long-term forecast of multi-issue global change (Hughes 1997)*, a look at the future of human development using the human development index and variations created for longer term forecasting (Hughes 2004 February), and analysis of sustainable development globally but with particular attention to Europe (Hughes and Johnston 2005)*, an analysis of Chinese policy around the Spratley Archipeligo (Senese 2005), an examination of likely global transitions in multiple issue areas (Hughes 2005 March), forecasting of demographic and economic drivers regionally and across the scenarios of the United Nations Environment Programme's Global Environment Outlook (Hughes 2005 June), an extended consideration of global and regional prospects for meeting the Millennium Development Goal on poverty reduction (Hughes and Irfan 2005 December), an investigation of the future of globalization (Hughes 2006 April), an analysis of political and development prospects for the Korean peninsula (Chadwick 2006), and a look at the future of global income distribution (Hillebrand 2006).

In addition to these "applied" forecasting works, there are two project papers that are more self-consciously focused on the quality of IFs as a forecasting instrument. The first (Hughes 2004 March) examines the base case forecasts of IFs relative to other forecasts in all of its key issue areas and explores the bases for differences and similarities. That was undertaken in part as background information for the National Intelligence Council's Project 2020 (US NIC 2004). The second was an analysis of scenario analysis with IFs (Hughes 2004 July), with special attention to the insights that the model provides with respect to growing tensions and what are sometimes called "inevitable surprises" (Schwartz 1991 and 2003).

3.2 Who has Access to and Has Reviewed IFs?

The documentation of IFs is thus quite extensive. A fair amount has been published and there is much in the "working paper" pipeline that should ultimately also move into formal print, but that is in the interim available on the IFs web site.

The most important release of documentation and information on IFs is, however, not in papers and publications, as essential as these are, especially for the stamp of approval from peer review. It is, instead, in the long-term availability of the model itself for use without restriction and the availability with the model of very extensive documentation in the Help system (see, especially, the Help book called "Understanding the Model: Opening the 'Black Box'"). From very early in the project an effort was made to provide a user interface that made it relatively simple to use the model. That interface has evolved dramatically over the years and has been, quite possibly, the single best investment of the project in making the model accessible. Users over the years have provided countless suggestions for improvement and enhancement in both model and interface, and, through their continued and expanded use, have implicitly said much about their assessment of the system's credibility.

Other world models have not had the availability of IFs. The most nearly comparable is the World 3 model that was the foundation for the analysis of *The Limits to Growth* (Meadows et al 1972 and Meadows et al 2004), which has also been freely available over a long period of time. That model's purposes were substantially different, of course, and it succeeded wonderfully with them (examining prospective limits to growth on a global basis). The IFs model has long been a much more disaggregated model geographically and much more detailed in its specifications, so as to allow something closer to policy analysis. For access to most of the other world models with any kind of public availability see the web site of Peter Brecke on Global Models (http://www.inta.gatech.edu/peter/globmod.html).

Users have fallen into two general categories. The first in temporal terms and the most numerous over time has been the original target audience for IFs, college-level students and their professors. The first releases of IFs, in the early 1980s, were written in FORTRAN and available for use on main-frame computers through CONDUIT, an educational software distribution center at the University of Iowa. The first microcomputer version, a stripped-down world-level only model was produced in 1985 and circulated quite widely. Full versions of the model with a representation of 14 different global regions, appeared for desktop computers in 1993, accompanied by the first book on the system's structure and use (Hughes 1993)*. For the next decade the model was provided on floppy disks, then later CDs and then via download from the web with subsequent editions of the text book. In 2004 the web-based version of the model appeared eliminating the need for download. Downloads of the software continue to be available.

Over that time period there is no way to know the number of individual college students and others who have used the model and there is even no tally of the number who have provided feedback in support of its enhancement. Based on sales of the book, the number of users has been several thousand. Many professors became repeat users of the system in their classes.

The second major category of user is those associated with various governmental organizations. Given that they, too, were able to acquire the model easily and at little or no cost, it is difficult to know how many may have examined it and/or used it. There are, however, a number of projects that built in a significant role for IFs. In the very first of these, the U.S. Foreign Service Institute used the first generation of IFs in a mid-career training program in the early 1980s.

More significantly and with a more research analysis orientation, several projects have looked to IFs for support since 2000. The European Commission sponsored the 3-year long TERRA project, with a focus on the New Economy and the unfolding of initiatives moving Europe and the world towards sustainability (Hughes and Johnson 2005)*. There were many institutions and teams involved, but IFs provided the principal modeling and forecasting tool. The Strategic Assessments Group (SAG) of the U.S. Central Intelligence Agency undertook a number of studies that drew on IFs, including a global demographic study, an examination of democratization, and a study of changing global power configurations. The National Intelligence Council subsequently looked to IFs for some support in its Project 2020. IFs is currently supporting the United Nations Environmental Programme's Global Environmental Outlook (GEO-4), due for release in 2007. And with sponsorship of Frederick Pardee the IFs project will team with the RAND Corporation for extended analysis of global poverty reduction and, subsequently of other aspects of global human development.

3.3 Conclusions about Documentation and Inspection

Chapter 2 discussed the critical role that documentation and inspection play in assessing the validity of a model. Every reader undertakes that activity to some extent. Even more, every user of the model, very often also a reader of the documentation, essentially undertakes their own analysis of its validity and verification. Repeat users not only continue to play such roles, but increasingly suggest the credibility that the system has gained. It should be readily acknowledged that many users inevitably found IFs to be too hard to use or discovered results that simply did not pass the "smell test" and therefore moved on. When users move from the hundreds into the thousands, however, and when a number of well-known institutions also adopt the system for roles in their own programs, the accrual of validity or credibility discussed by Hodges and Dewar (1992) increasingly occurs.

But what about historical testing and analysis? In spite of some of the problems associated with that, already discussed earlier, it is important. We move to it next.

4. Testing and Analysis: Historical Calibration/Validation

A world model greatly simplifies the world system and therefore will inevitably be flawed in its representation of global processes. In addition, of course, many forecasts of the model might roughly track real-world patterns for entirely the wrong reasons. Nonetheless, comparison of processes as forecast in the model with those that have unfolded in the world is an important test of the model. That is the purpose of this chapter.

4.1 The Foundations and Expectations

There are three foundations for historic evaluation of results from IFs:

1. The IFs database. Data for all areas of the model have been collected for 182 countries, insofar as possible, from 1960 through the most recent year. There are, of course, very large numbers of holes in this database and very weak/error-prone data for many series and countries. For instance, many countries in 2000 did not even exist in 1960, but rather were part of disintegrating empires of the European powers or countries such as the Soviet Union, Yugoslavia, and Czechoslovakia that would themselves disintegrate. Insofar as possible, the IFs database was built by estimating values for the countries of 2000 over the entire 1960-2000 period (in some cases proportionately allocating pre-disintegration values on the basis of post-disintegration relative sizes).

2. The IFs data preprocessor. This important part of the IFs modeling system (Hughes 2006 May) cleans and reconciles data needed to initialize the model in its starting year. The code finds large numbers of data problems even for the 2000 load. For the 1960 data load of the model the problems are enormous. For instance, there is essentially no input-output data for the economic model in 1960. The preprocessor has been programmed to use 1960 data when available and to prepare estimates of 1960 values from later ones when they are not. Similarly, there were no life tables for population from 1960, so life expectancy and infant mortality were used to compute them as best possible. Very substantial estimation and hole-filling is done by the preprocessor for the 1960 load.[2]

3. The IFs interface. The interface allows comparison of historic series with computed series for the large number of data series with direct analogues in the model's forecasts. This allows plotting of history and forecasts together and fairly simple direct comparisons of them.

[2] Unfortunately, the data from the 1960s through 2000 are sufficiently weak that a large portion of the effort behind this chapter to compare historical forecasts with empirical data was devoted to building the initial data load and the run for 1960-2000, not actually to fixing/calibrating the IFs model in ways that will enhance its forecasting beyond 2000.

The process for comparing actual historical data with historical forecasts of IFs involves initializing the model in 1960 and running it with a very limited set of interventions through 2000. It is important to be clear about the types of interventions that are "allowed." For instance, some historical validation processes with models actually readjust the starting values of the model each year. They therefore are, in essence, only forecasting one year at a time, not allowing the model to drift away from historic trajectories over long periods of time. They compute the error of the model only year by year.

In the process with IFs, such adjustments are not made. Instead, a limited number of interventions are introduced so as to represent events or processes that are essentially not within the ability of the model to forecast. One example is the movement of China to 2-child and then 1-child families in the period between 1960 and 2000. The model cannot forecast such a political decision and the intervention needs to be exogenous; without an intervention the population of China would have been substantially different in 2000. Another example is the oil shocks of the 1970s and 1980s. Although it is reasonable to think that a model should have been able to foresee some of the tightening of the world energy markets in the 1970s (just as the Shell Scenario Group foresaw the movement of Iran from focusing on production increases to emphasizing revenue increases; see Wack 1985a and 1985b), it is not reasonable to expect that a simulation run beginning in 1960 could foresee the Middle Eastern war of 1973 and the resultant oil embargo.

The actual nature of interventions needed in IFs to reasonably well represent the 1960-2000 period without such events/processes being endogenous to the model provides important information about the strengths and weaknesses of the system for forecasting beyond 2000. Thus this chapter will list all of those interventions and dissect their implications.

Another option for historical validation work with IFs was theoretically possible. It is common, for instance, to undertake "split sample" work. The training of neural network models often uses one historic period for training and another for testing, a process that is particularly important for such models that do not have an obvious and transparent causal structure. In the case of IFs, the entire historic period for which data are available is used because the purpose of IFs is forecasting not just for the 20 years of a split historic sample or even the entire 40 years of the full historic sample, but rather through the end of the twenty-first century. [3] Using the longest historic period possible for testing and calibration makes sense in such a situation.

[3] Some parameters are calculated using data from 1960 through 1980.

4.2 Process and Results

It is useful to understand the sequence of the historical testing and calibration effort. Because of the close interaction of all parts of the model, it needed to be iterative, beginning in some areas of the model, proceeding to others, and sweeping back for a second and even third pass. For the most part, demographics and economic modules were the starting point because those modules affect all others and are, in turn substantially affected by most others. The expectations of the historical comparison, to be shown in the next sections of the chapter, are to match historic forecast and actual historic values reasonably well with respect to total population and GDP growth and a few additional key demographic and economic variables for the world and the largest countries.

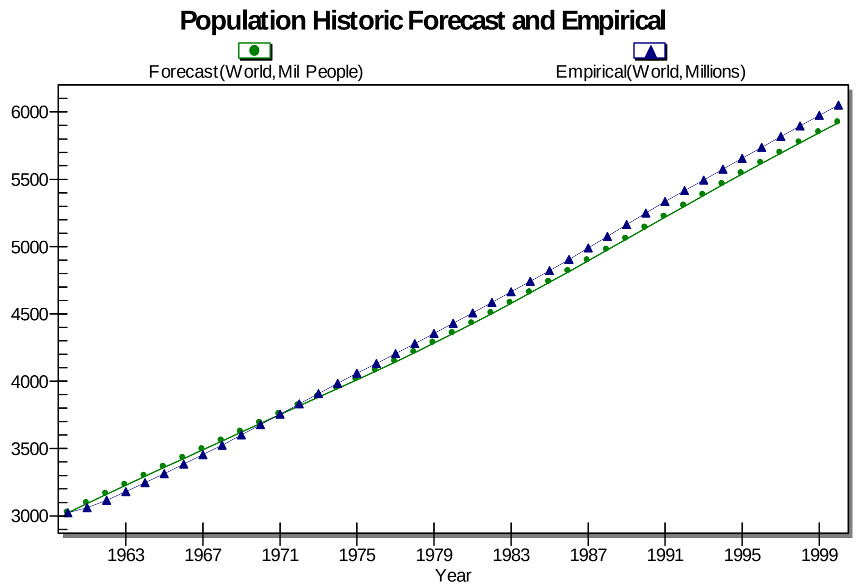
The process of historical testing and calibration, and the attention of this chapter, turn next to the agricultural, energy, environmental, and sociopolitical modules. These have fewer direct interactions with each other. Some of the key variables in these modules are food demand and consumption levels (focusing on calories per capita), energy demand and production levels, carbon emissions, and a variety of sociopolitical variables including governance (such as democracy), educational attainment, and the human development index (even though it was not developed until the last decade of the century).

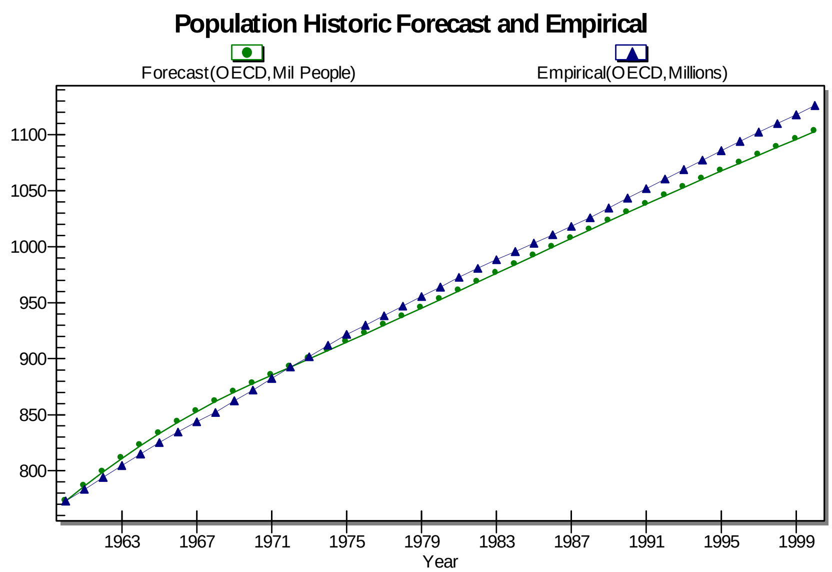
For the most part the largest countries in the relevant issue area (e.g. China and India in demographics, the U.S. in economics, the OPEC countries in energy) were given special attention. It is not possible to consider testing and calibrating 182 countries across all variables of the model. Once again, these validation/calibration activities are an ongoing, never-ending process.

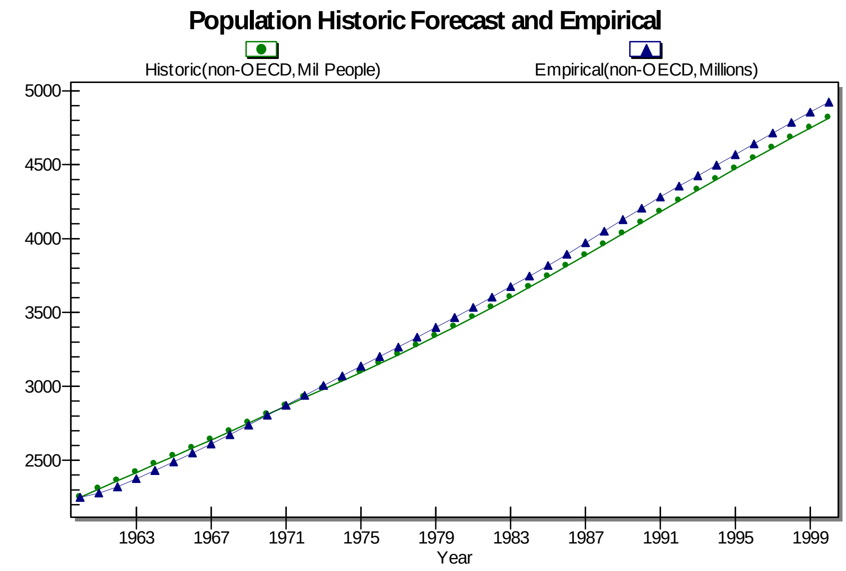
4.3 Population

The first three graphs below, as in most other issue areas, show a central variable, in this case population for the world, for OECD countries (membership of today across all time), and for non-OECD countries. That first cut helps show the degree to which the model is capturing the general dynamics in both rich and poor countries, respectively. Subsequent graphs will in this and each following section single out additional regions or specific countries for additional attention. In most cases, the additional graphs will include China and India, two contemporary demographic giants and emerging global superpowers. Each graph will show the IFs historical forecast (in green) along with the relevant empirical series.

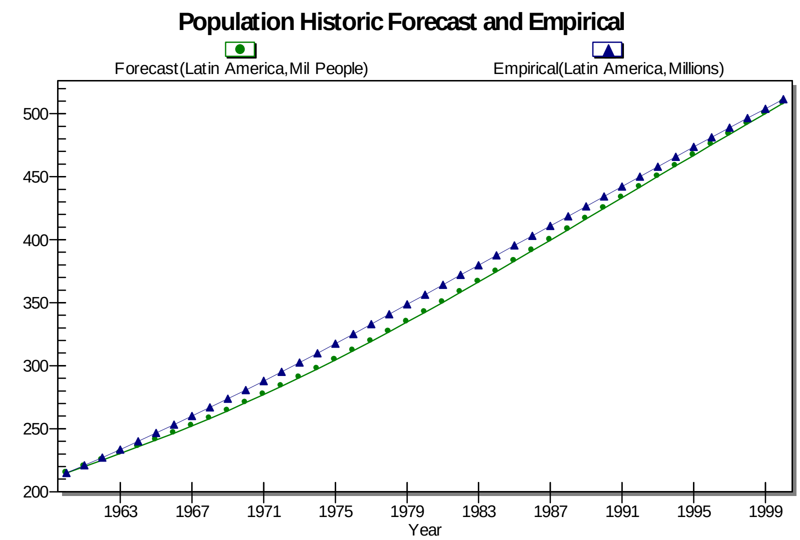
Figures are provided with little commentary, in part because the desired fit to history is subjective. Demographics is one of the easier areas in which to obtain reasonably good historic results, because fertility and mortality rates change relatively slowly in most circumstances.

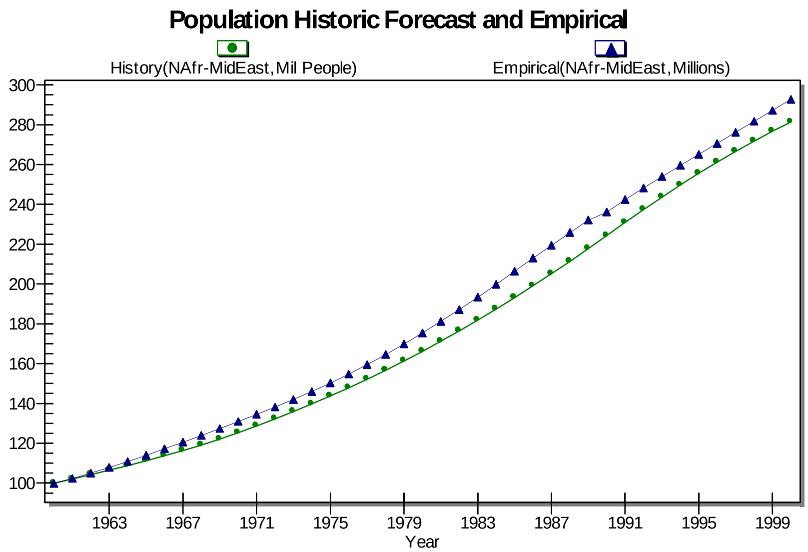

Population Historic Forecast and Empirical
Forecast(World,Mil People)
Empirical(World,Millions)
6000
5500
5000
4500
4000
3500
3000
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

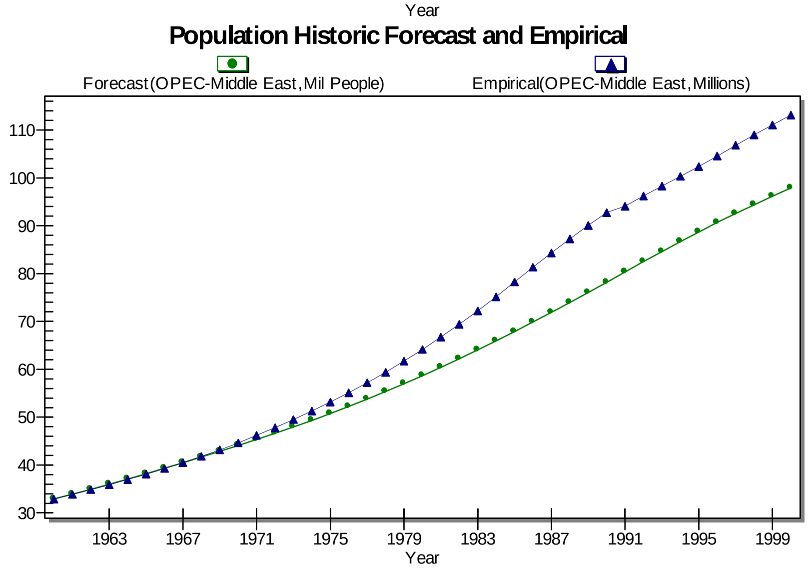

Population Historic Forecast and Empirical
Forecast(OECD,Mil People)
Empirical(OECD,Millions)
1100
1050
1000
950
900
850
800
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

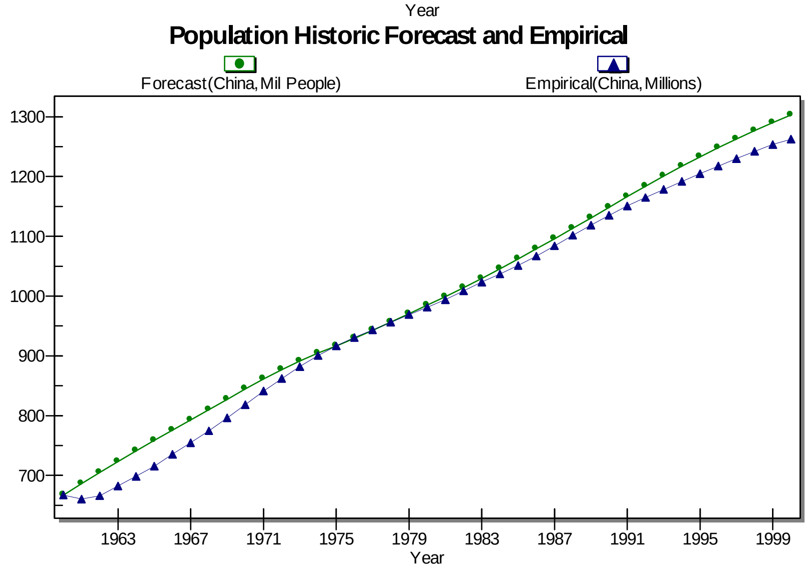


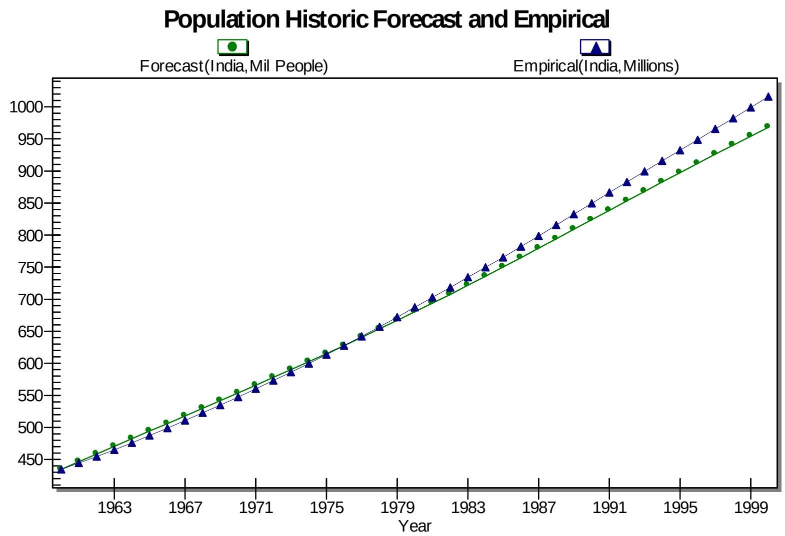
Looking inside the non-OECD country set, where most of the world's population falls, the following figures show the results for Latin America, North Africa and the Middle East (where a number of problems arose to be discussed below), the OPEC countries of the Middle East (as a subset of the prior set), China and India.




Population Historic Forecast and Empirical
History(NAfr-MidEast,Mil People)
Empirical(NAfr-MidEast,Millions)
300
280
260
240
220
200
180
160
140
120
100
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

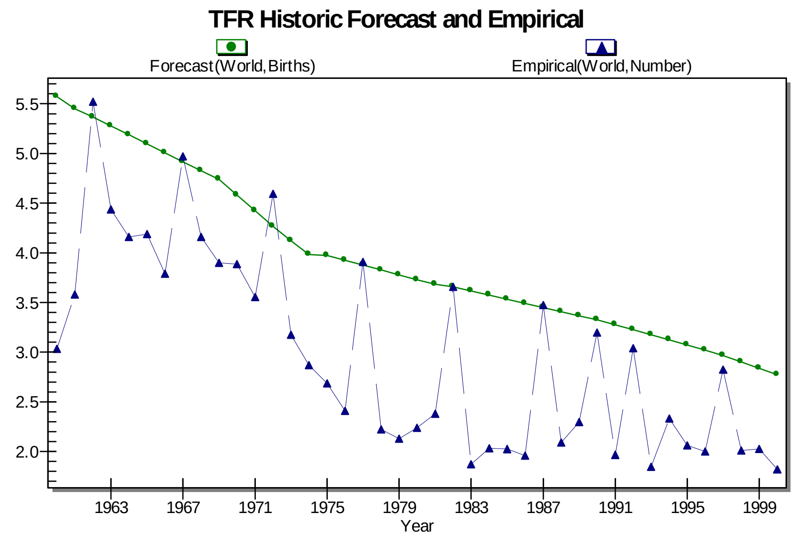

Population Historic Forecast and Empirical
Forecast(OPEC-Middle East,Mil People)
Empirical(OPEC-Middle East,Millions)
110
100
90
80
70
60
50
40
30
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

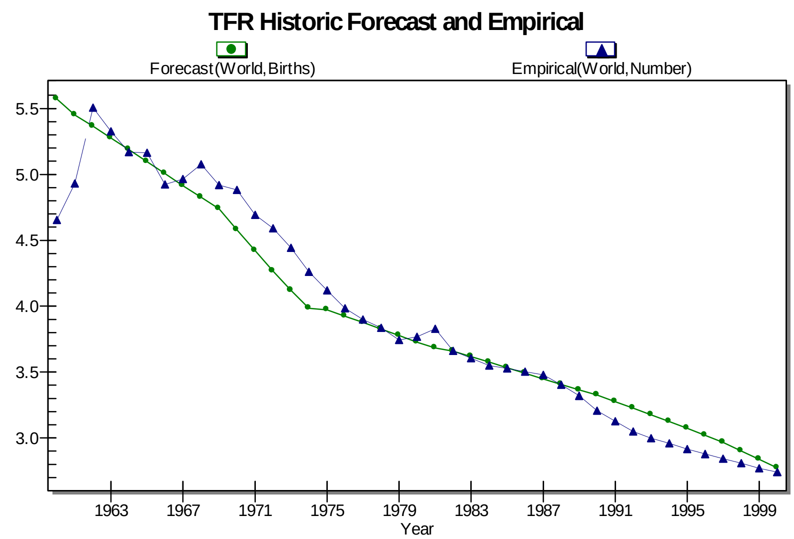

Population Historic Forecast and Empirical
Forecast(China,Mil People)
Empirical(China,Millions)
1300
1200
1100
1000
900
800
700
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

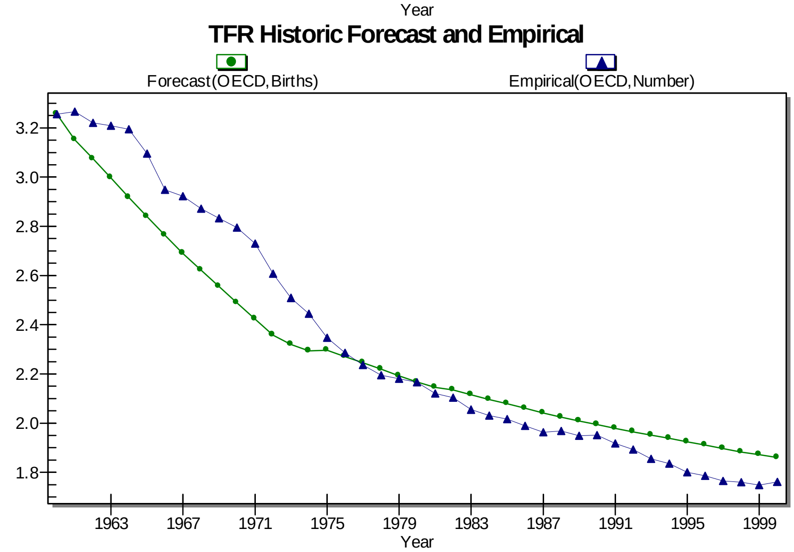


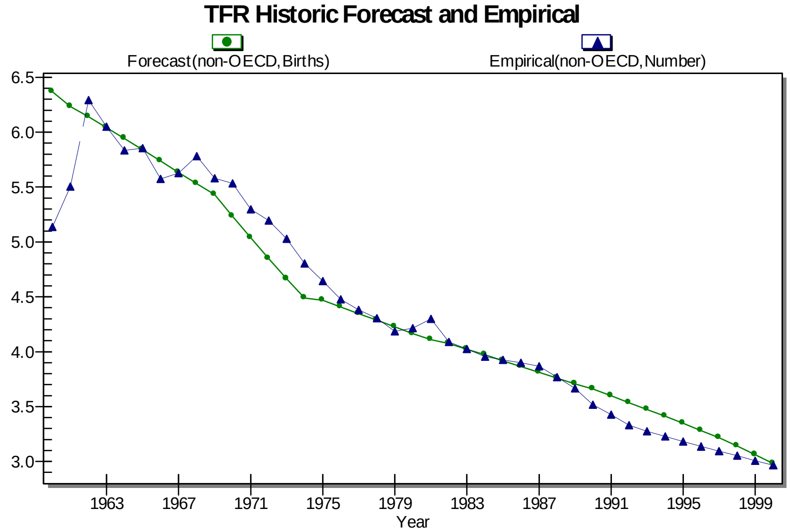
The above graphs show the results of the model dynamics with a relatively small number of interventions. Because of its great importance for demographics, most of those interventions were made with respect to fertility rates. The graphs below show historic forecast and empirical values, again for the world, OECD, non-OECD, and selected other countries or country sets, after the interventions. The specific interventions are presented and discussed after the figures.

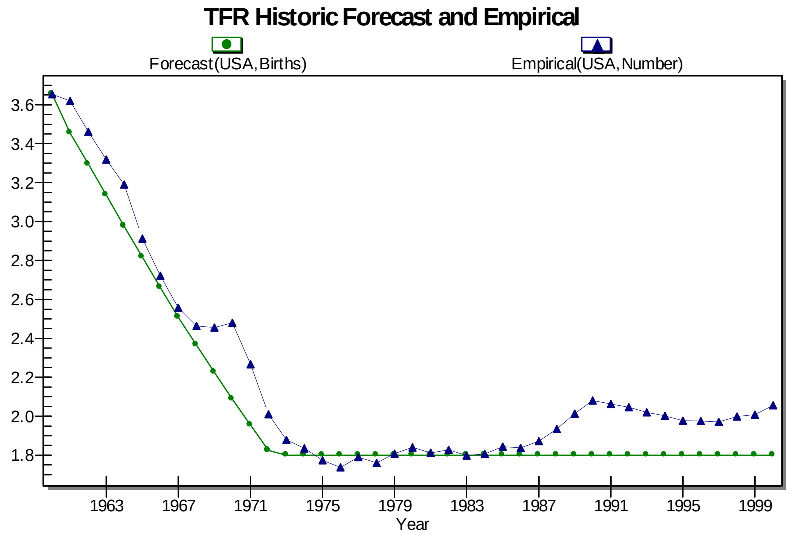
Note the great irregularity of the historic data in the figure for the world, immediately below. In the case of TFR and a fair number of other variables, there are a great many missing data. The peaks of the pattern over time are the population-weighted averages for years in which most countries report. The troughs generally represent years in which fewer countries report; the missing countries in the troughs are most often poorer, smaller countries with higher fertility rates, so that values in those years are lower than the actual world averages would be – compare the IFs forecast with the peaks. In many of the subsequent graphs, we have used a new capability within IFs to fill data holes with a combination of interpolation and extrapolation techniques; although not perfect, such graphs give a better idea of the fit of historic forecasts from IFs and the probable values of underlying variables that we want generally to match.

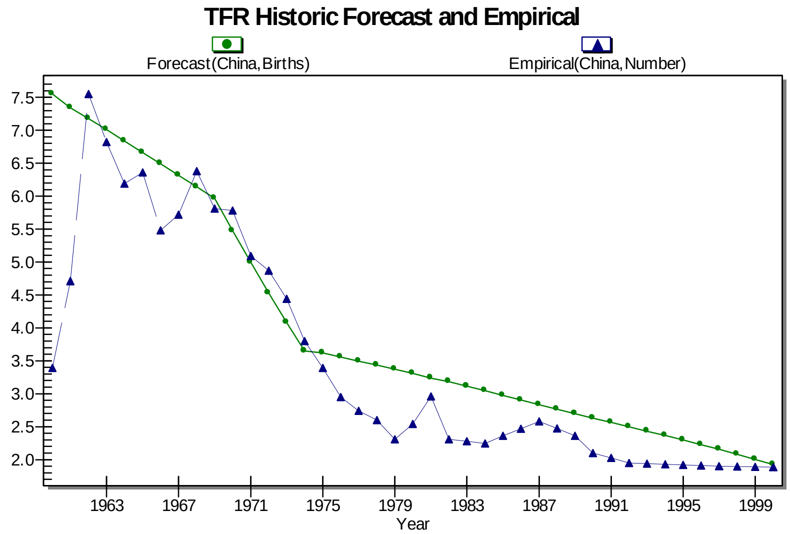

TFR Historic Forecast and Empirical
Forecast(World,Births)
Empirical(World,Number)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

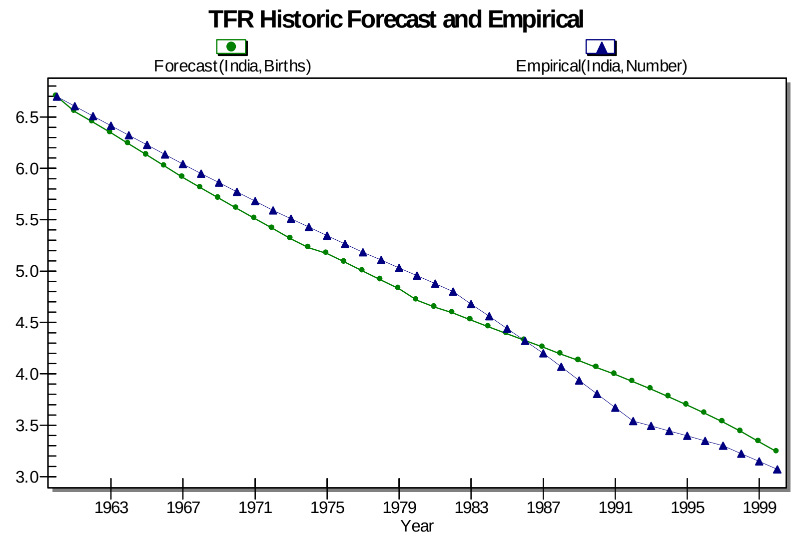

TFR Historic Forecast and Empirical
Forecast(World,Births)
Empirical(World,Number)
5.5
5.0
4.5
4.0
3.5
3.0
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


TFR Historic Forecast and Empirical
Forecast(OECD,Births)
Empirical(OECD,Number)
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


TFR Historic Forecast and Empirical
Forecast(non-OECD,Births)
Empirical(non-OECD,Number)
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


TFR Historic Forecast and Empirical
Forecast(USA,Births)
Empirical(USA,Number)
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


TFR Historic Forecast and Empirical
Forecast(China,Births)
Empirical(China,Number)
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year



The specific interventions for the entire testing/calibration process are in a file called IFsHist.Dat on the /Data subdirectory of the model installation. In the case of the fertility rate, the interventions were:

TFR,China,7.55,7.55:200
Comment, Must eliminate 1960-61 Great Leap Forward data
ttfrr,-.001,-.0005@40,-.0005:100
TFRM,China,1,.9@9,.6@5,.6:100
TFRM,India,1,.85@20,.85:100
TFRM,USA,1,.6@15,.6:200
TFRM, NAfr-MidEast, 1, 1.5@30,1@10,1:100

In the above lines, the name of the variable or parameter to be changed is followed, when appropriate by a country, country-grouping or other sub-dimension and then by values. The first value will always be for the year 1960. Values followed by an @ sign and a number (such as 0.85@9 instruct the model to interpolate the intervention to the value before the @ sign over the number of years following the sign. Values followed by a colon and a number instruct the model to repeat the intervention before the colon across the number of years following the colon.

The above interventions accomplish the following:

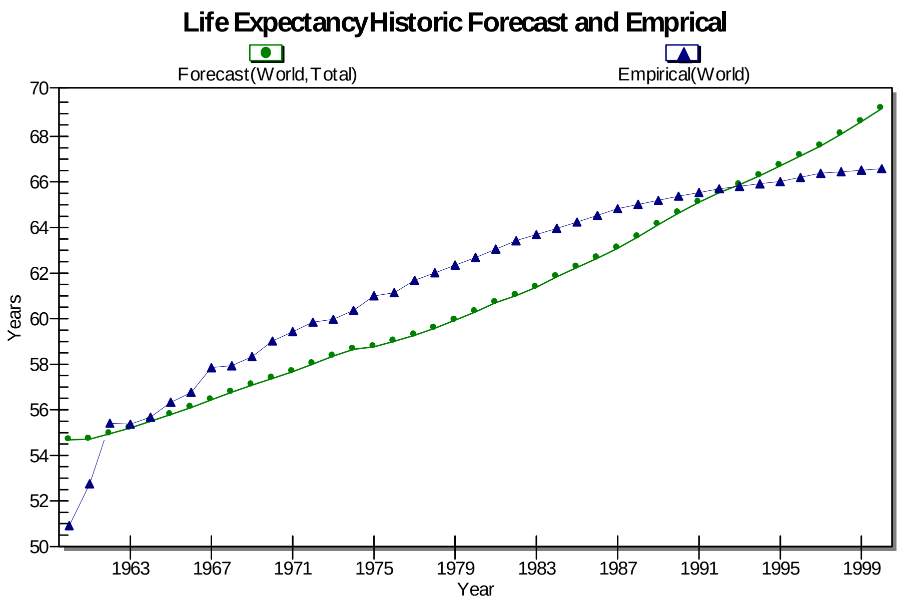
- Set the initial value of total fertility rate (TFR) in China at 7.55 in 1960; the Great Leap Forward led to highly distorted demographic patterns in 1960. The preprocessor for data automatically initializes all model values with 1960 data when available, so this intervention replaces that value with the one from 1962.

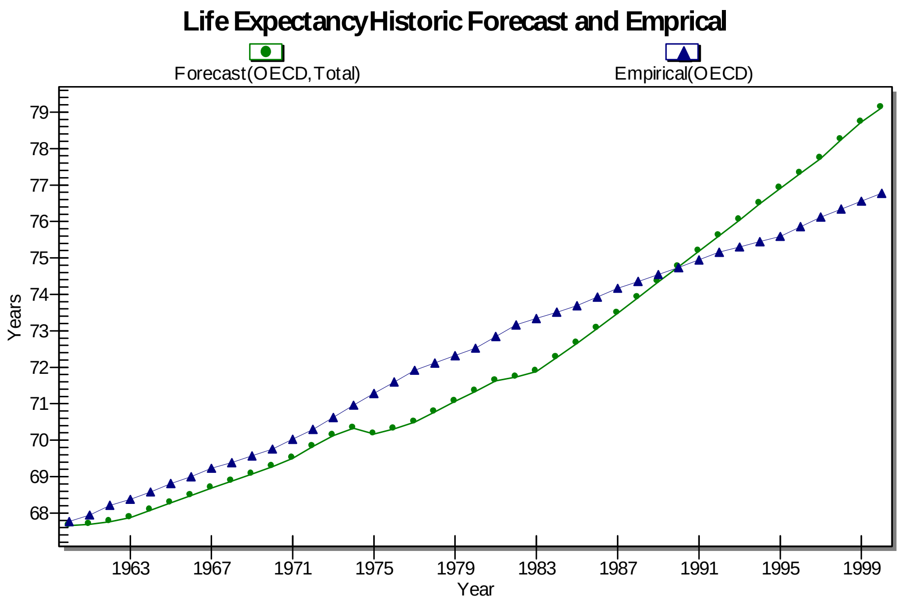
- The parameter for a time trend adjustment to fertility rates (ttfrr) works on a global basis. It is given small negative values that decrease to even smaller ones over time. The reason this is needed is that global fertility patterns shifted downward quite dramatically over the historic period as global momentum for family planning gradually grew. This is something that almost certainly will not be repeated in the future.

- The multiplier on total fertility rate for China (TFRM) begins at 1.0, indicating no intervention. But after 10 years it begins moving sharply downward as China moved into 2-child per family "voluntary" and then 1-child per family programs. A smaller, slower intervention is made for India, which pursued family planning fairly ardently as well. Interestingly, an intervention was also needed for the United States, for which fertility fell much more rapidly in the 1960s and early 1970s than the formulations in the model anticipated. This is largely because (1) post World War II baby-boom rates going into the 1960s were unusually and temporarily high (causing an initialization problem) and (2) a variety of social changes in the 1960s, including especially some in women's roles, brought fertility down sharply.

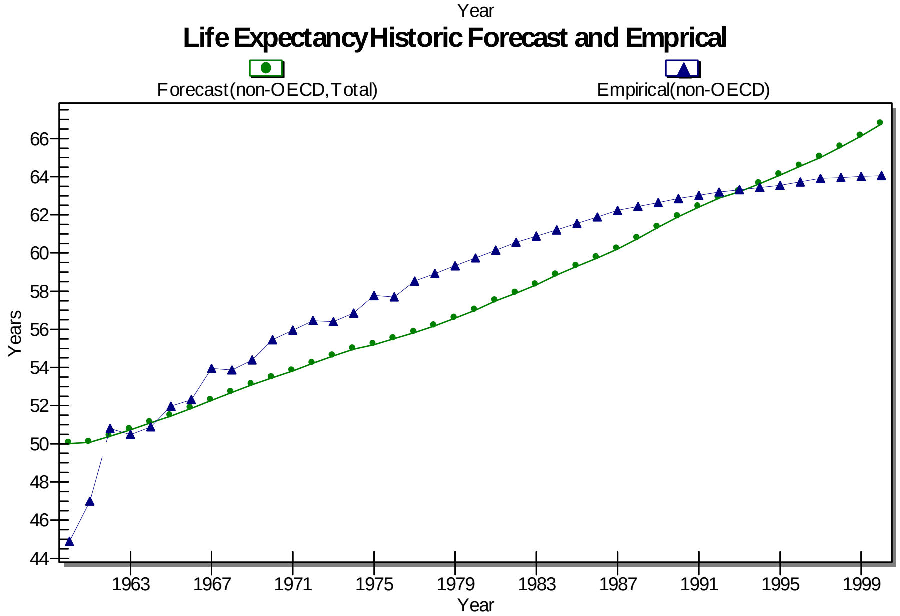
- In contrast to the patterns for China, India, and the US, in North Africa and the Middle East it was necessary to rather sharply raise fertility rates above those otherwise anticipated by the model. The reasons certainly combine (1) cultural factors and (2) political-economic factors, namely the impact of state oil revenues via welfare systems on well-being even when those revenues did not actually affect income (the model ties fertility rates to GDP per capita, not income per capita).

Turning below to life expectancy, the forces affecting it tend to be more global and therefore fewer interventions were necessary (the are described again following the graphs).

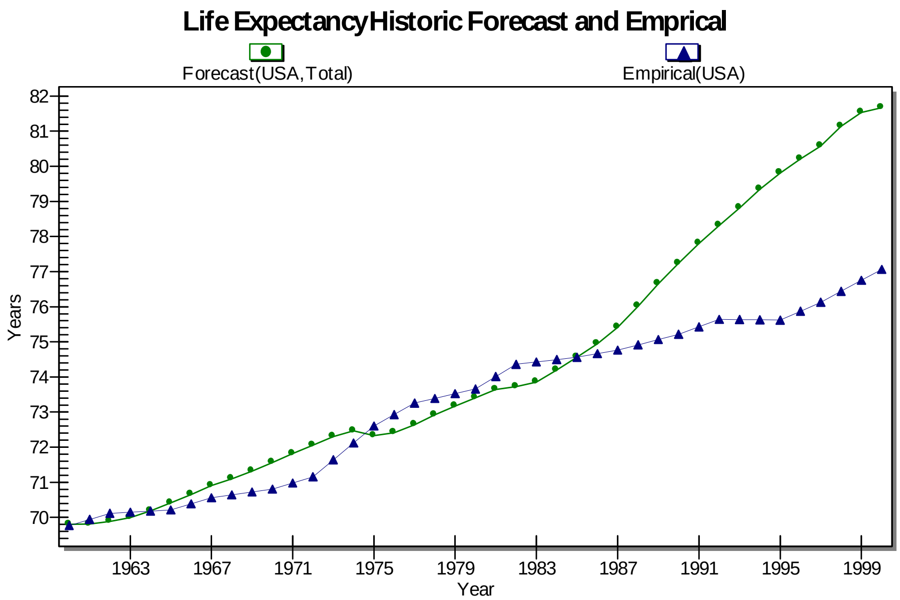


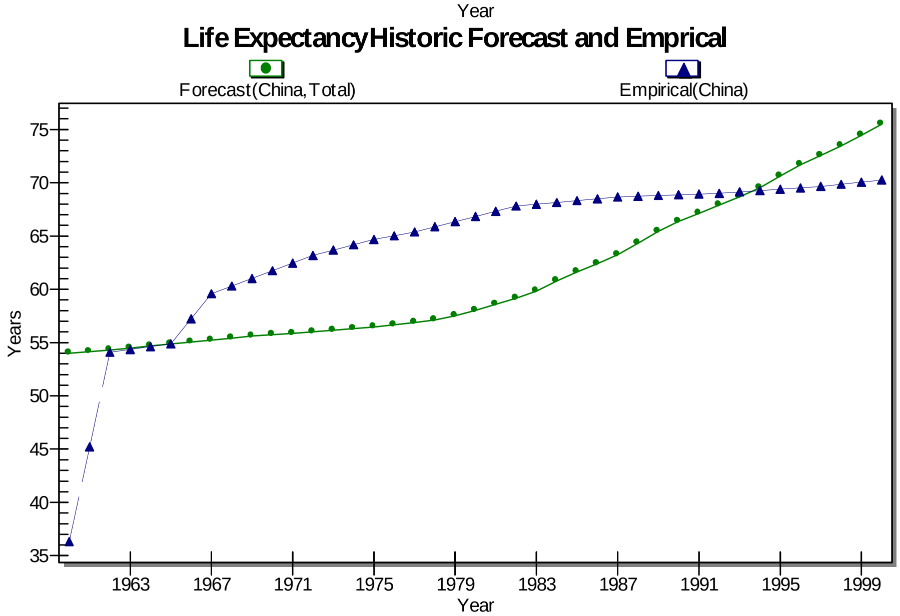


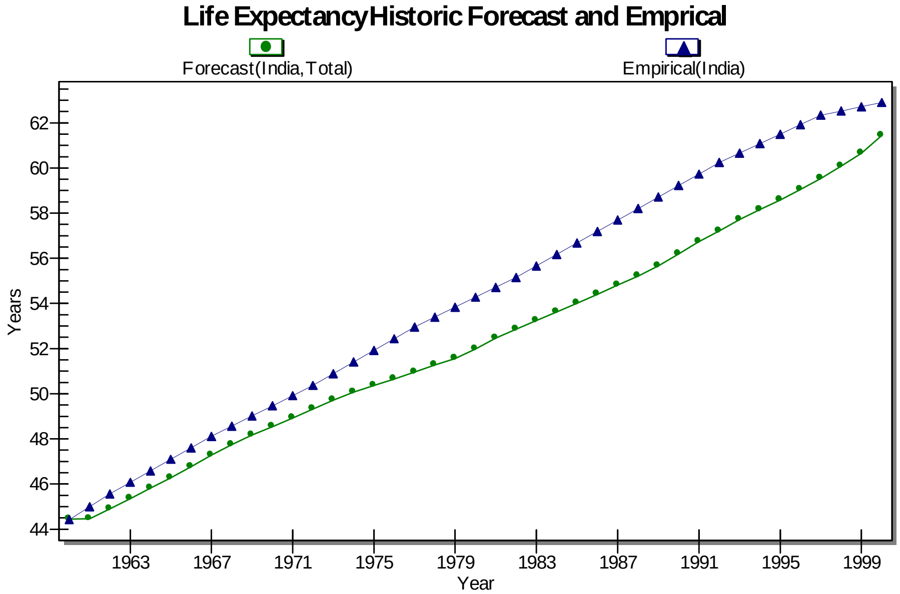
Life Expectancy Historic Forecast and Emprical
Forecast(OECD,Total)
Empirical(OECD)
Years
79
78
77
76
75
74
73
72
71
70
69
68
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year



Life Expectancy Historic Forecast and Emprical
Forecast(non-OECD,Total)
Empirical(non-OECD)
Years
66
64
62
60
58
56
54
52
50
48
46
44
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


Life Expectancy Historic Forecast and Emprical
Forecast(USA,Total)
Empirical(USA)
Years
82
81
80
79
78
77
76
75
74
73
72
71
70
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


Life Expectancy Historic Forecast and Emprical
Forecast(China,Total)
Empirical(China)
Years
75
70
65
60
55
50
45
40
35
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

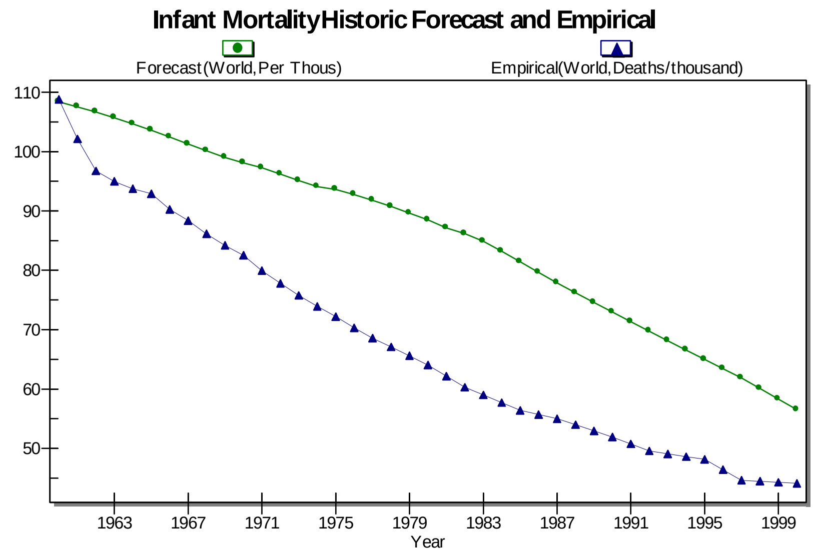


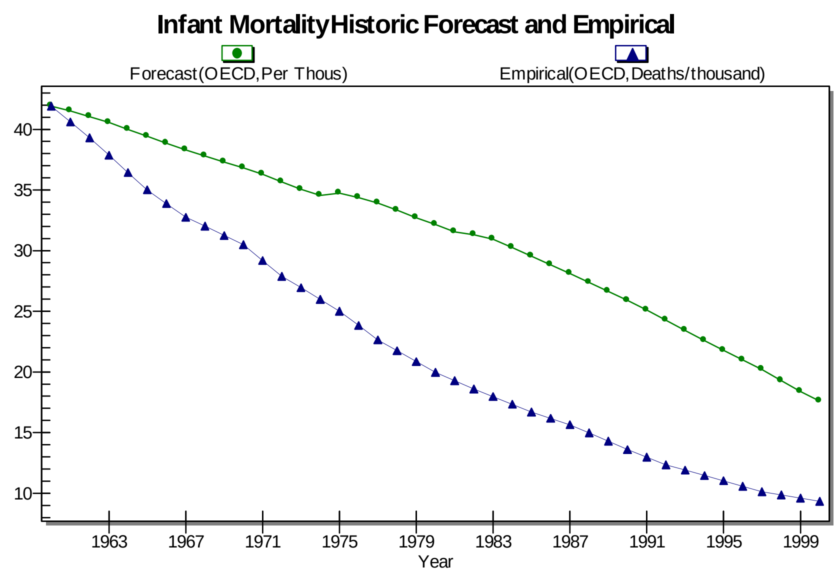
LIFEXP,China,54.05,54.09:200
Comment, Must eliminate 1960 GLF data point
tmortr,-.0005,-.0001@40,-.0001:100
tmortr2,-.005,-.005@40,-.005:100

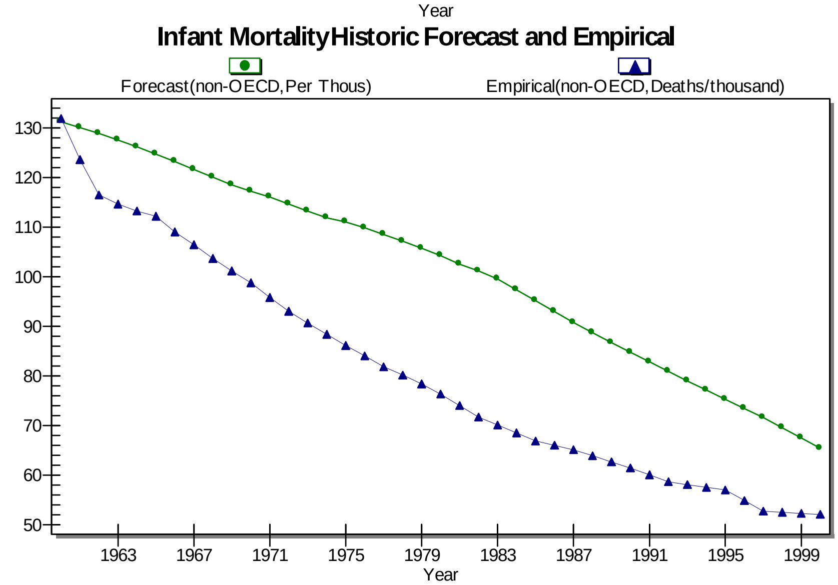
The specific interventions did the following:

- Reset Chinese life expectancy to offset the devastating impact of the Great Leap Forward on values in 1960.
- Introduce a global time trend (tmortr) with small reductions in mortality initially and increasingly small ones over time, to generate the rapid rise in life expectancy seen during this period as sanitation, nutrition, and medical technology advanced.
- Introduce a larger time trend for developing countries specifically (tmortr2) as decolonization progressed and the same advances swept very rapidly into the newly independent states.

The figures below show reductions in infant mortality, one of the key forces in the expansion of life expectancy around the world. Although the IFs historic forecast captures much of the drop, it underestimates it. This forecast could be improved, which would also reduce the needed general mortality interventions indicated above. One of the problems in undertaking historic forecasts of infant and more general mortality is that the UN Population Division, the source of IFs data, does not provide survivor tables for 1960. For the purposes of the historic analysis, we swapped in infant morality rates to achieve appropriate initial conditions, but other death rates actually represent those of about 1990.


Infant MortalityHistoric Forecast and Empirical
Forecast(World,Per Thous)
Empirical(World,Deaths/thousand)
110
100
90
80
70
60
50
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


Infant MortalityHistoric Forecast and Empirical
Forecast(OECD,Per Thous)
Empirical(OECD,Deaths/thousand)
40
35
30
25
20
15
10
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

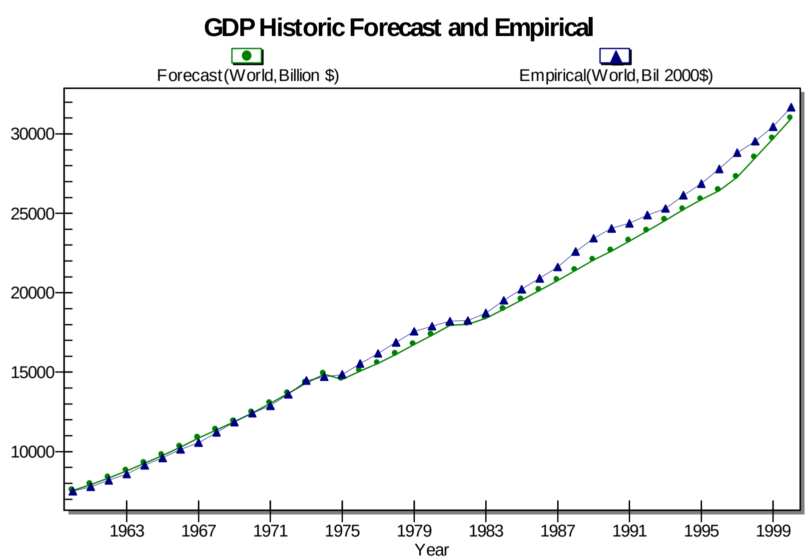

Infant MortalityHistoric Forecast and Empirical
Forecast(non-OECD,Per Thous)
Empirical(non-OECD,Deaths/thousand)
130
120
110
100
90
80
70
60
50
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

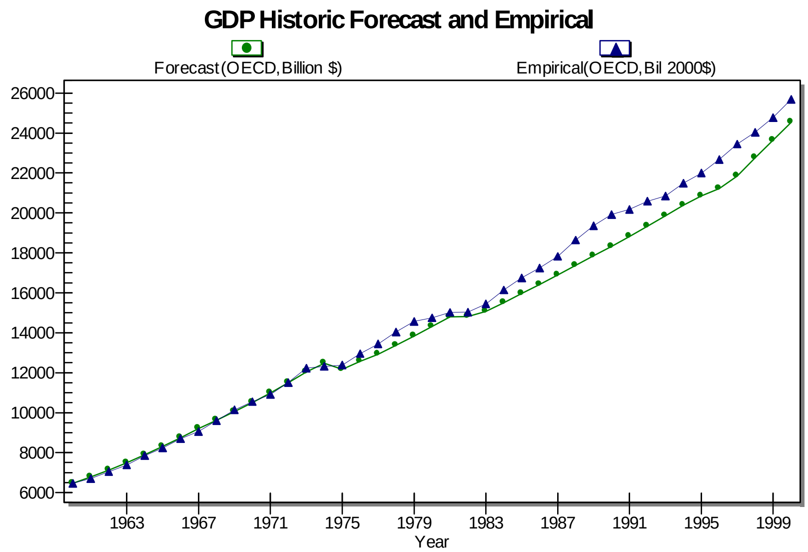
One last set of interventions affected all of the demographic forecasts shown above. In addition to fertility and mortality, the third flow that affects demographic patterns, at least at the country level and to a lesser degree at the global level, is migration. Migration flows tend to be lumpier and more irregular than births and deaths and therefore to be less easily forecast. IFs relies heavily on UN data on migration, both for historical analysis and forecasting from 2000. Although the model has mechanisms to assure that global flows are balanced and also to allow user interventions, it does not attempt to anticipate shifts in flow patterns. Therefore in the historical analysis IFs simply uses UN data for each country as an exogenously specified flow (the preprocessor assures global balance). The extract below from the IFsHistFull.dat file indicates that intervention for Afghanistan, a country characterized by a long historic pattern of outward flows.

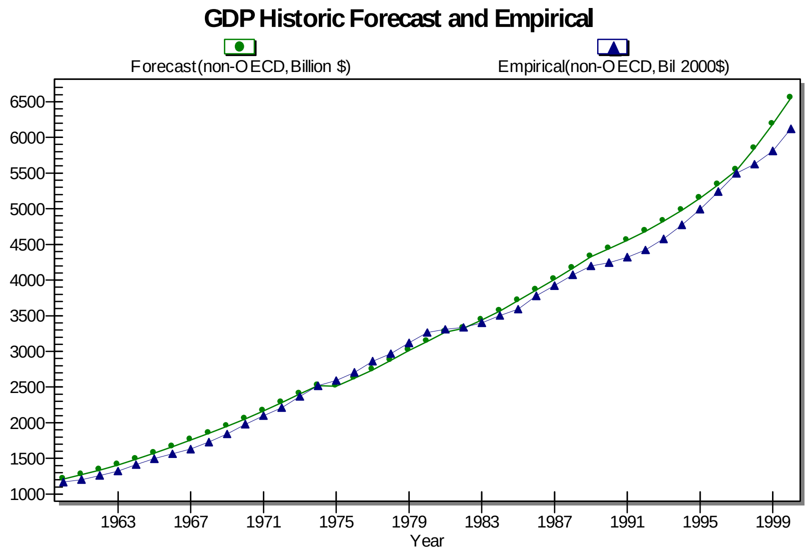
migrater,"Afghanistan",0,-6.53811005008273E-02,-.130762201001655,-.196143301502482,-.261524402003309,-.326905502504137,-.392286603004964,-.457667703505791,-.523048804006619,-.588429904507446

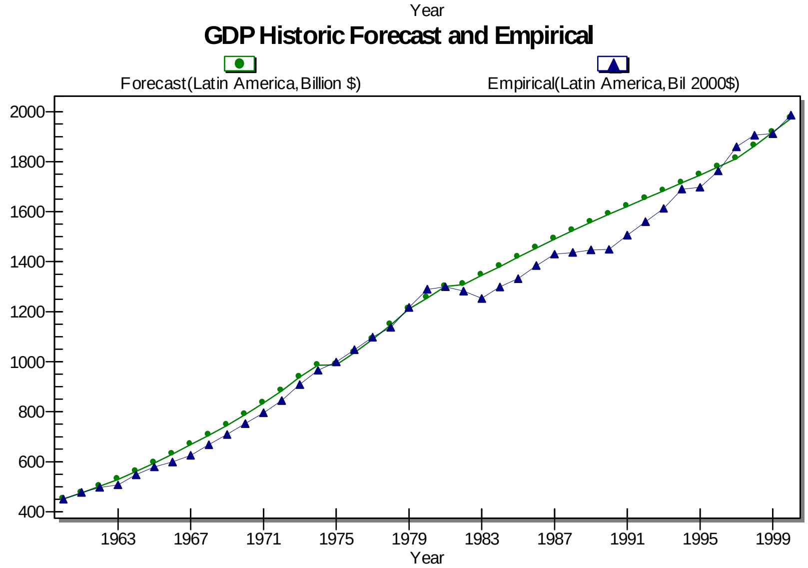
4.4 Economics

Turning to the economics submodule of IFs, the central variable is gross domestic product (GDP). The three graphs immediately below show historic forecasts and empirical values for the world, OECD countries, and non-OECD countries.

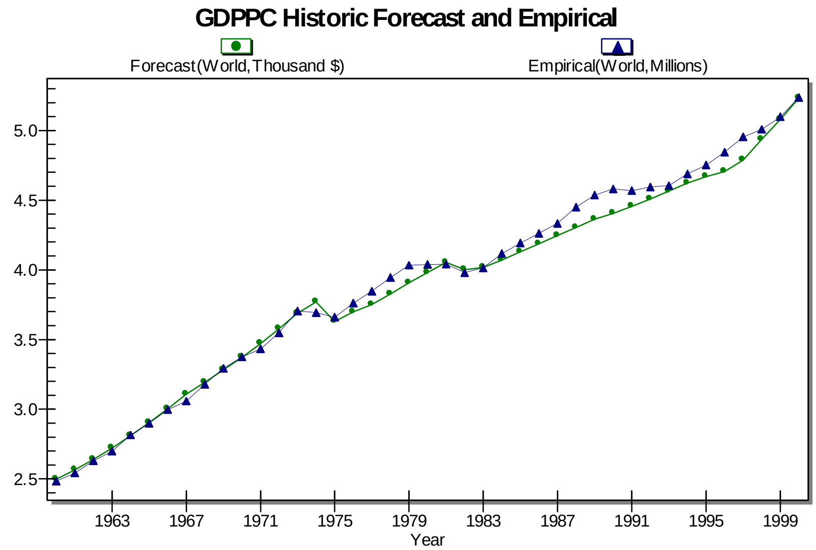



GDP Historic Forecast and Empirical
Forecast(OECD,Billion $)
Empirical(OECD,Bil 2000$)
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


GDP Historic Forecast and Empirical
Forecast(non-OECD,Billion $)
Empirical(non-OECD,Bil 2000$)
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


GDP Historic Forecast and Empirical
Forecast(Latin America,Billion $)
Empirical(Latin America,Bil 2000$)
2000
1800
1600
1400
1200
1000
800
600
400
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

The figure below shows GDP per capita for the world simply as an indication of how the combination of GDP and population fits of historic forecasts to empirical values translates into the key variable affected by both.



It is more difficult to fit the model to historic economic data than it is to fit it to historic population data. Economies are affected by a vast range of forces, not least of which are government decisions. Among the most fundamental forces driving economic growth rates, however, is the rate of advance in technology and of productivity associated with it.

Although IFs has mechanisms for endogenizing much of multifactor productivity growth specific to countries, it does not attempt to forecast changes in long-term technological growth of the global system. Instead it uses an approach (described in Hughes May 2005) that posits a leading country with respect to technological change, historically and in current forecasts the United States. There is a large literature on long waves of global technological advance and, whether or not such waves do exist, the period between 1960 and 2000 was characterized by one major shift in rates of productivity advance. Specifically, near the end of the 1960s, productivity advance dropped from historically high rates associated in part with catch-up from World War II (the Golden Age of Angus Maddison 2001), to substantially slower rates that characterized the US and most of the world until the mid to late 1990s. The interventions below use data from the U.S. National Bureau of Economic Research (NBER) to set values of multifactor productivity growth in the U.S. by sector (agriculture, energy, other primary materials, manufactures, services, and the ICT). In the model, these values for the systemic leader affect all other countries in the global system through processes of global diffusion.

MFPLEADR,1,.015:200
MFPLEADR,2,.0242:8,.0146:6,.0015:24,.0116:100
MFPLEADR,3,.0242:8,.0146:6,.0015:24,.0116:100
MFPLEADR,4,.0242:8,.0146:6,.0015:24,.0116:100
MFPLEADR,5,.0242:8,.0146:6,.0015:24,.0116:100
MFPLEADR,6,.03:8,.05:6,.07:24,.1:100

A wide range of economic policies also greatly affect productivity growth. Not least are policies with respect to trade liberalization. During most of the period from 1960 through 2000 there was ongoing liberalization of global trade. The interventions below represent a decreased protection multiplier (PROTECM) for the world and also increased export promotion (XSHIFT). An additional intervention represents the even more substantial trade liberalization of China.

PROTECM,World,1,1:20,.8@20,.8:100
XSHIFT,World,0:20,.03:20,.03:100
PROTECM, China,1,1:19,.5@5,.5:100
XSHIFT,China,0:20,.04:100

Liberalization occurred internally as well as externally, in ways that varied substantially across countries. While the United States and Europe liberalized during much of the period, China and India did so later in the historical period, the former communist countries (or transition economies) resisted it until very near the end, and North Africa and the Middle East largely stood apart from it. A multiplier on economic freedom (ECONFREEM) represents variations from levels that would have been expected based on level of GDP per capita. In addition, a multiplier (INVM) is introduced to capture the huge increase in investment rates within China during the historic period.

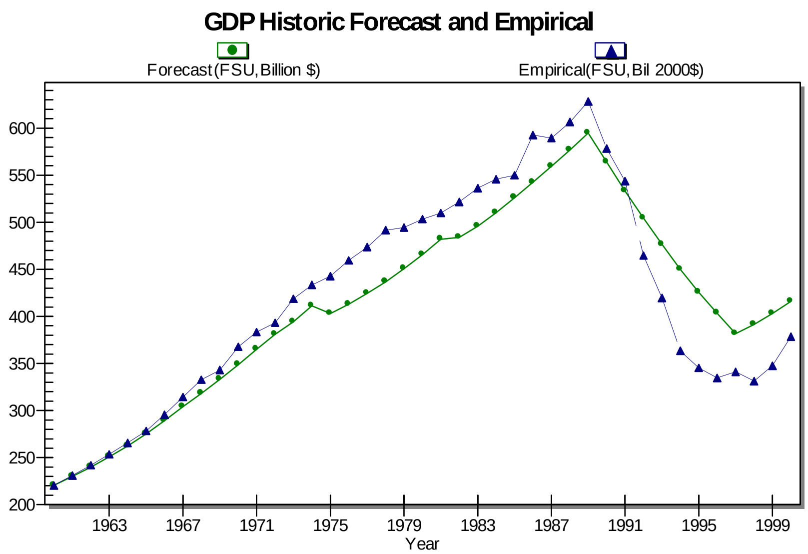
ECONFREEM,India,1,.9@15,1.1@25,1.1:100
ECONFREEM,EU15,1,1:10,.8@10,1.1@20,1.1:100
ECONFREEM,Afr-SubSahar,1,1.1@10,.95@10,1.2@20,1.2:100
ECONFREEM,Latin America,1,.7@15,.7:15,1@10,1:100
ECONFREEM,NAfr-MidEast,1,.9@10,.65@10,.65:10,.85@10,.85:100
ECONFREEM,Trans Econs,1,.65@30,.9@10,.9:100
ECONFREEM,China,1,.8@19, 1.05@20,1.05:100
ECONFREEM,USA,1,1:15,1.05@10,1.2@15,1.2:100
INVM,China,1,2.0@20,2.6@20,2.6:100

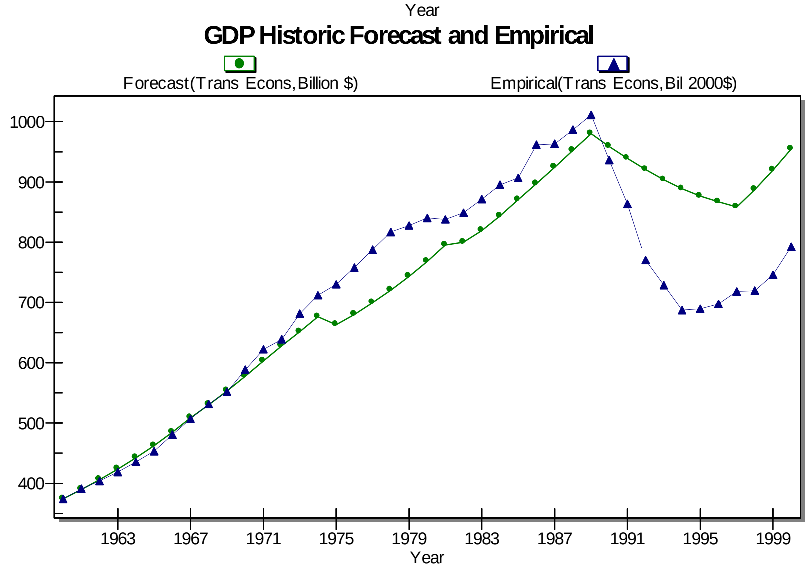
Even with the above, mostly policy-oriented interventions, there are significant differences between historic forecasts and empirical patterns. Therefore further additive adjustments were made to the multifactor productivity (MFPADD) of various countries and regions. Among the most significant residual adjustments were downward ones for sub-Saharan Africa (representing, depending on the analyst, geographic and/or governance forces) and a number of the OPEC countries of North Africa and the Middle East. This last set of adjustments is the most “ad hoc” of all those made in historical analysis of the economic module and would therefore be a focal point of further calibration efforts and model development.

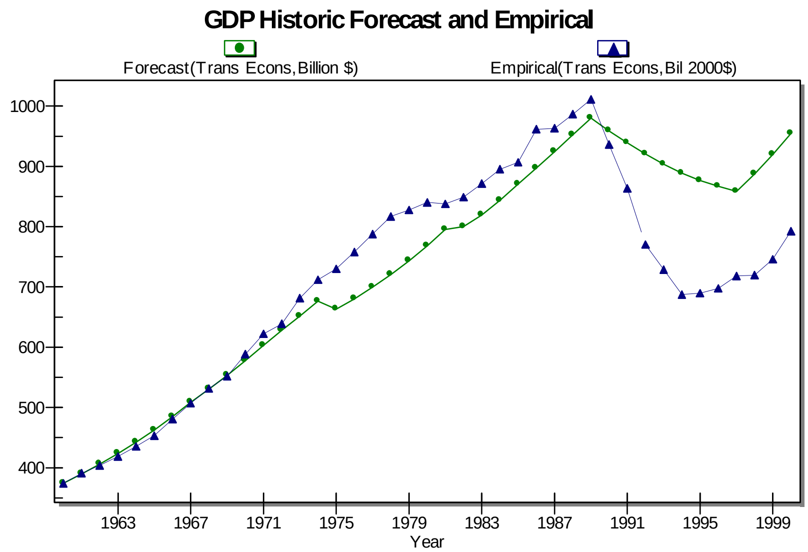
MFPADD,CHINA,0,0:20,.015:100
MFPADD,Taiwan,0:20,-.03:200
MFPADD,India,0:20,.03:200
MFPADD,Japan,0:30,-.015:200

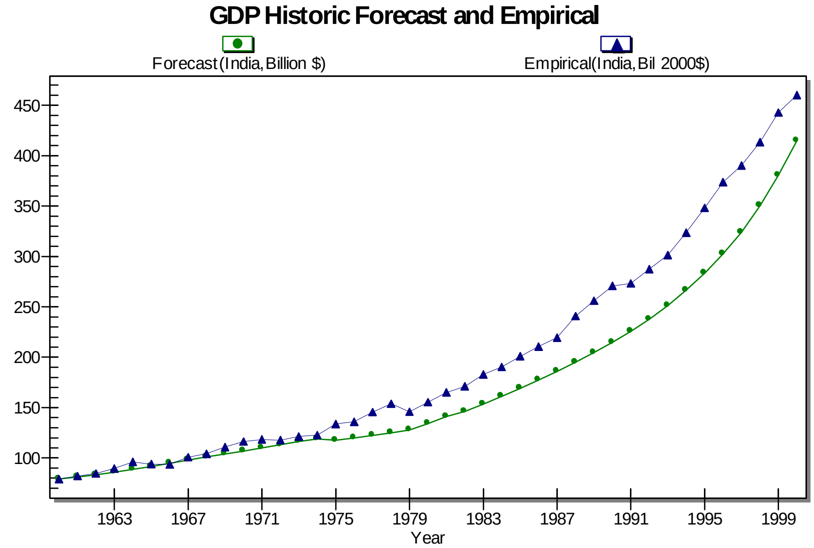
MFPADD,Afr-SubSahar,0:20,-.02:200
MFPADD,Amer-South,0:20,-.01:200
MFPADD,Brazil,0:20,-.03:200
MFPADD,Mexico,0:20,-.02:200
MFPADD,Amer-Carib,0:20,-.04:200
MFPADD,FSU,0:30,-.1:8,0:200
MFPADD,Iran,0:20,-.03:200
MFPADD,Saudi Arabia,0:20,-.02:100
MFPADD,Iraq,0:30,-.1:100
MFPADD,Algeria,-.015:200

With its basic structure and this set of interventions, the historic performance of the economic model is, on the whole, rather reasonable. For instance, the two graphs immediately below show the GDP of the former Soviet Union and the transition economies more generally. The two immediately below those show the GDP of China and India.

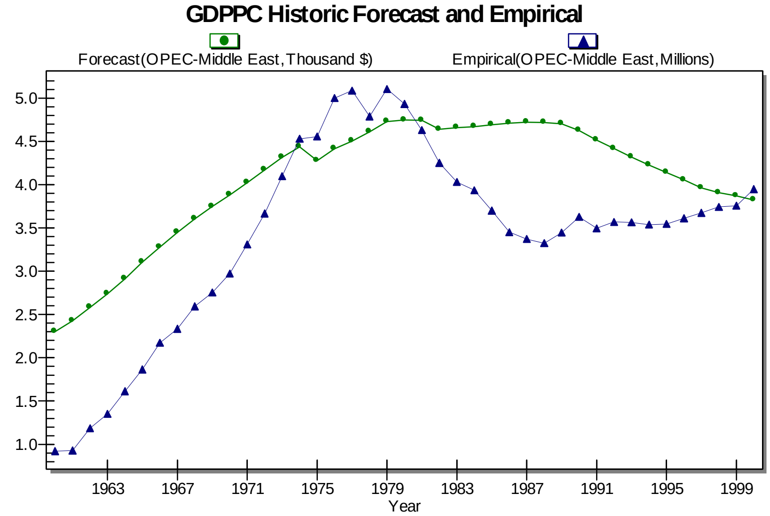


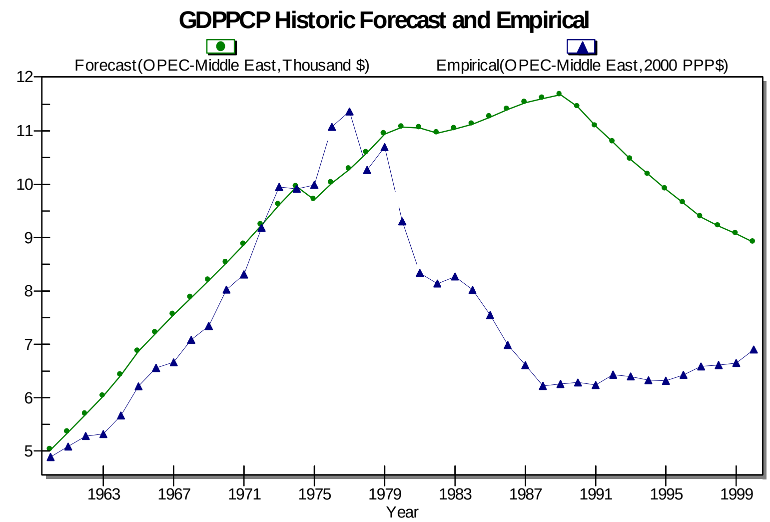




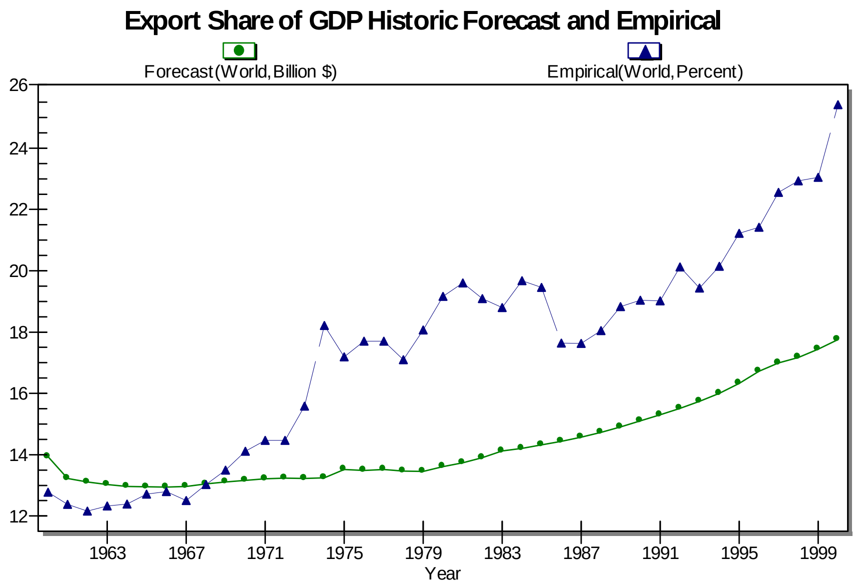


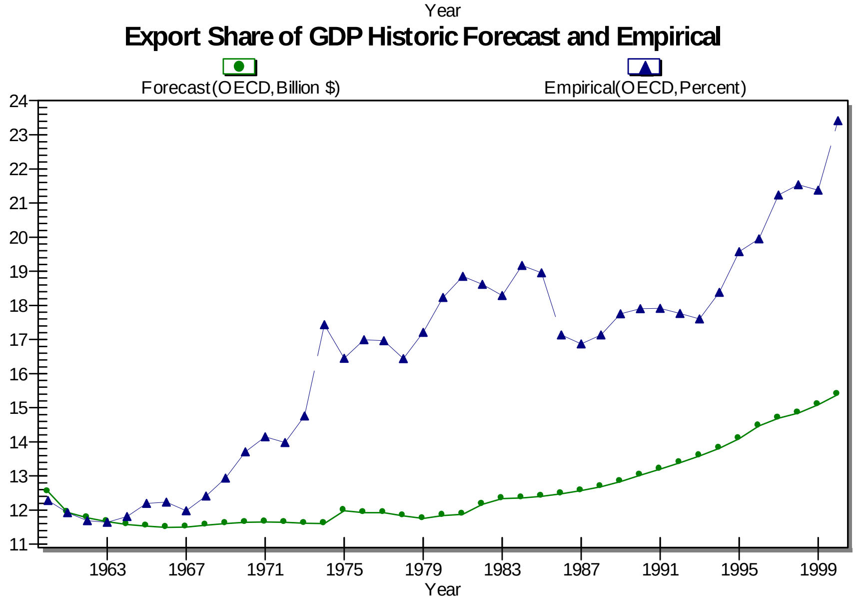
Calibration of a model to complex historic performances is a potentially never ending process. The two graphs below show GDP per capita at market prices and purchasing power parity for the OPEC countries of the Middle East. The values at purchasing power parity in particular could use further attention and work.





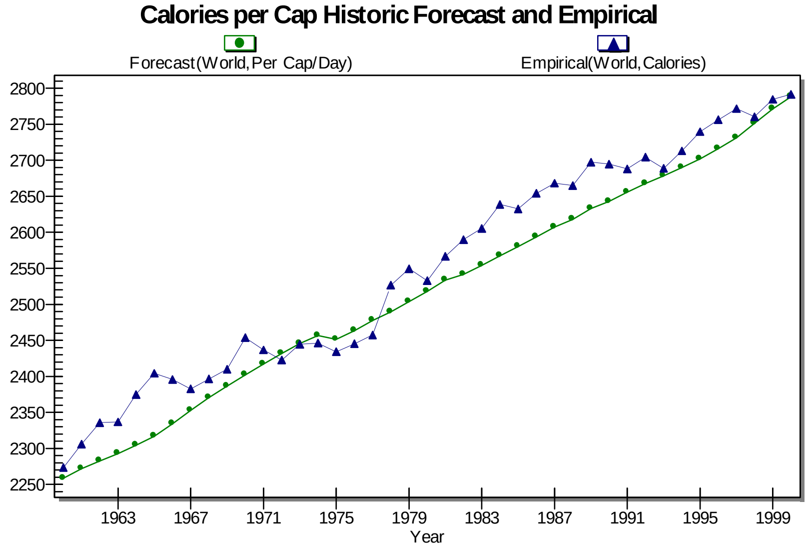
One additional area where further calibration work is needed is around trade. The two figures below show global exports and those of OECD countries as a share of GDP (in this case we did not use the historic estimation procedure, but rather the raw data). The growth of exports as a share of GDP in the historic forecast is quite a bit slower than it was in reality.

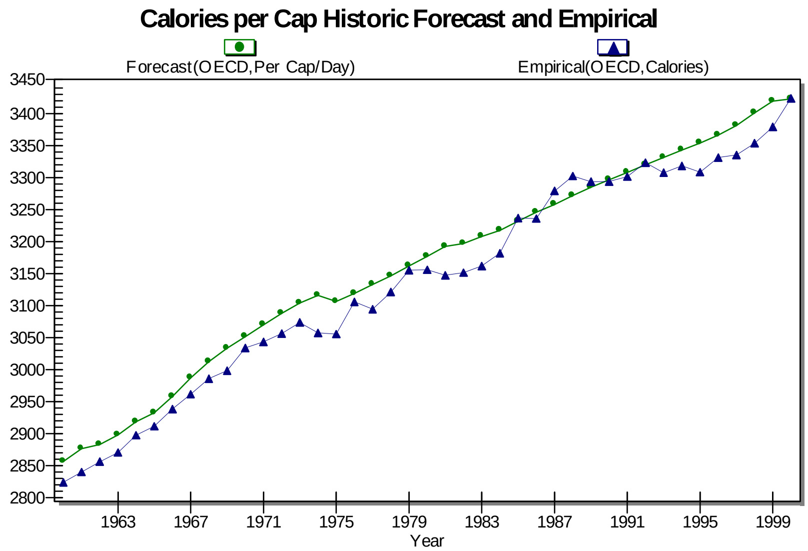


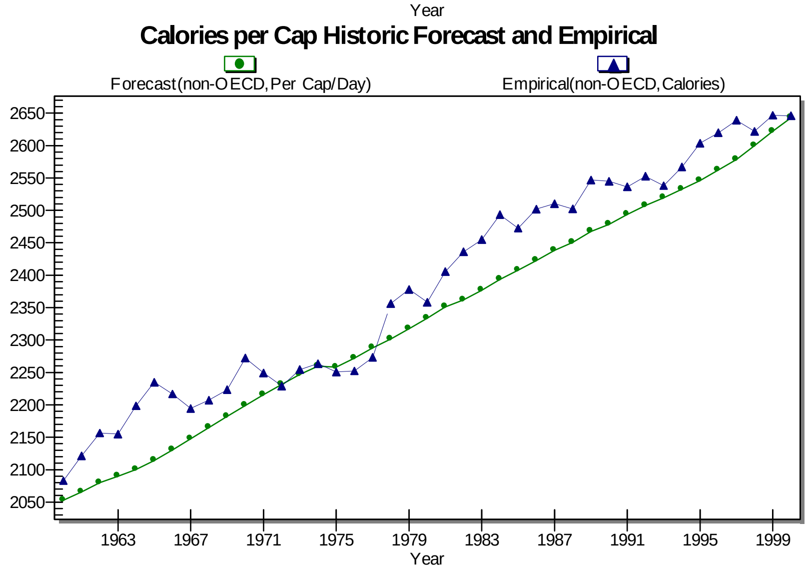


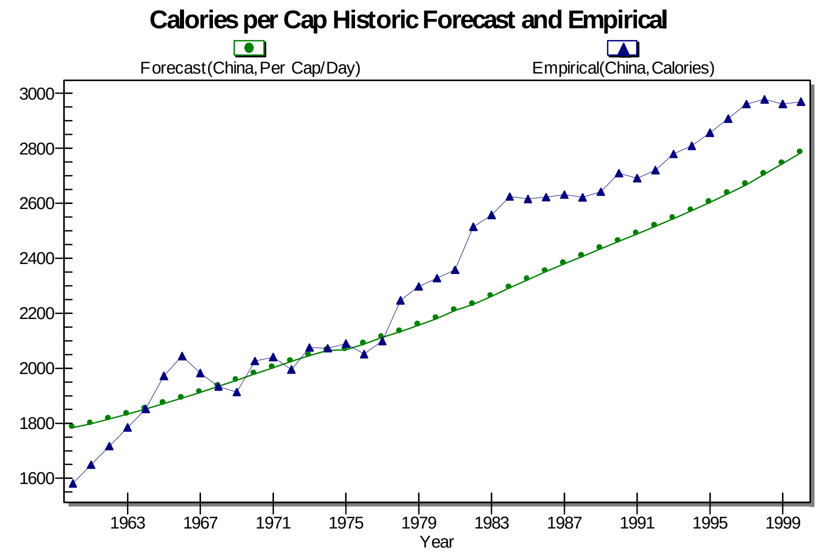
4.5 Food and Agriculture

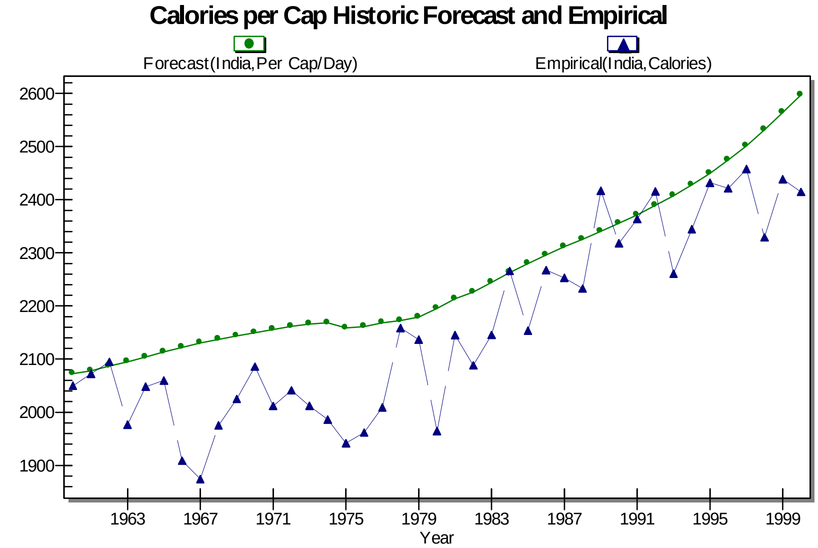
The food and agricultural model of IFs represents the demand for and supply of crops, meat and fish. The central variable for agriculture is calories available from these sources and the five graphs below show the historic forecast and empirical values for the world, OECD countries, and non-OECD countries, as well as for China and India. No interventions in the model were made with respect to calibrations for the historic forecasts – even though there are substantial political interventions in the agricultural sectors of both rich and poor countries, these appear not to change as dramatically over time as those in economics and energy, and even in population, do. Therefore model initialization appears adequate to capture most of those patterns.


Calories per Cap Historic Forecast and Empirical
Forecast(World,Per Cap/Day)
Empirical(World,Calories)
2800
2750
2700
2650
2600
2550
2500
2450
2400
2350
2300
2250
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

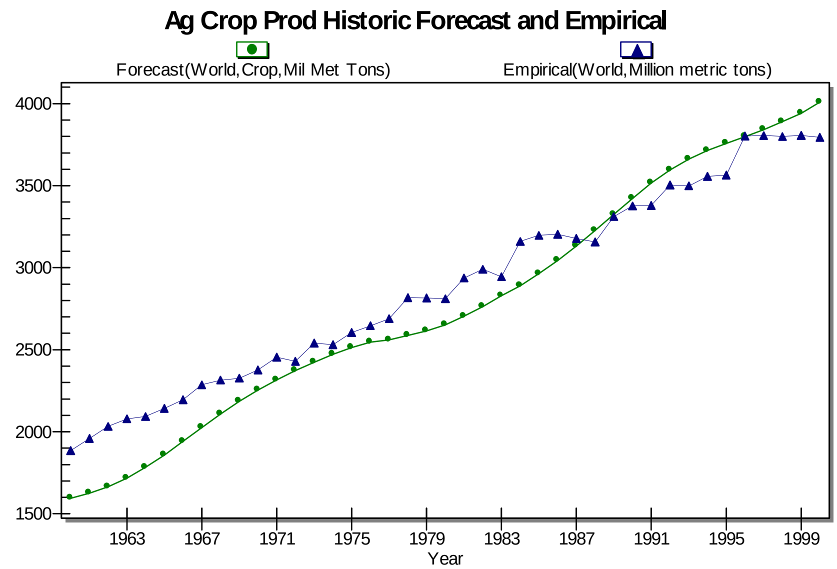

Calories per Cap Historic Forecast and Empirical
Forecast(OECD,Per Cap/Day)
Empirical(OECD,Calories)
3450
3400
3350
3300
3250
3200
3150
3100
3050
3000
2950
2900
2850
2800
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


Calories per Cap Historic Forecast and Empirical
Forecast(non-OECD,Per Cap/Day)
Empirical(non-OECD,Calories)
2650
2600
2550
2500
2450
2400
2350
2300
2250
2200
2150
2100
2050
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

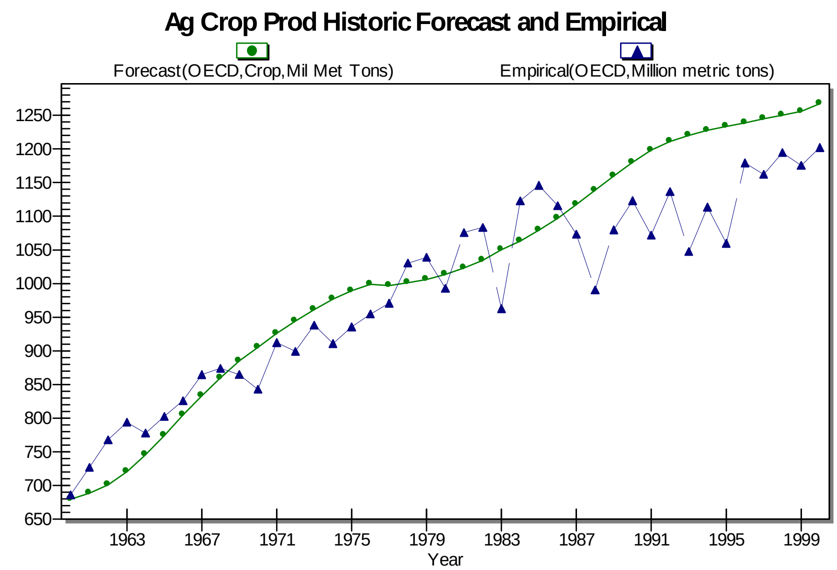




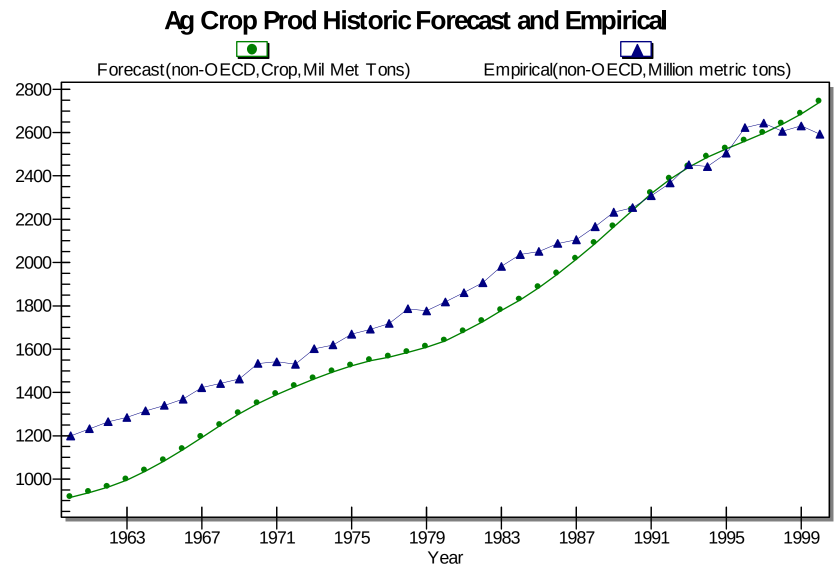
The primary proximate driver for food availability is crop production and the five graphs below show the production of crops for the same five geographic groupings and countries.

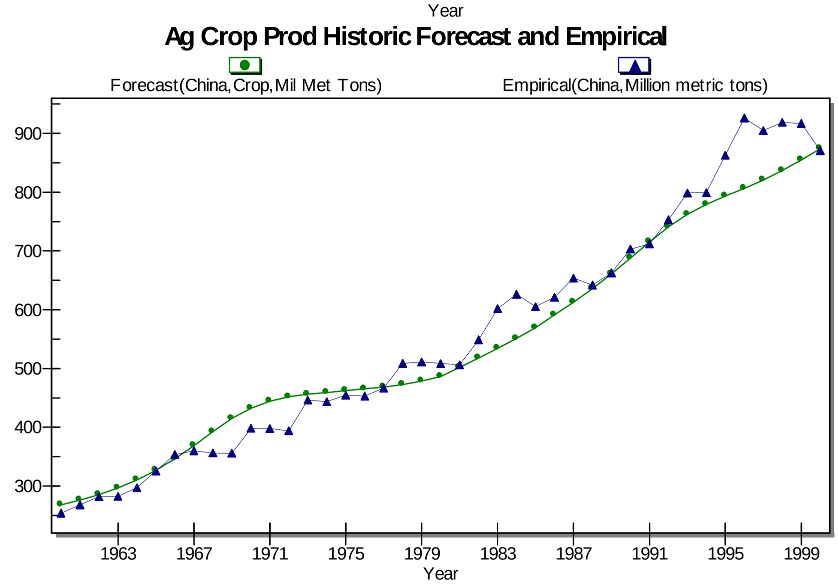


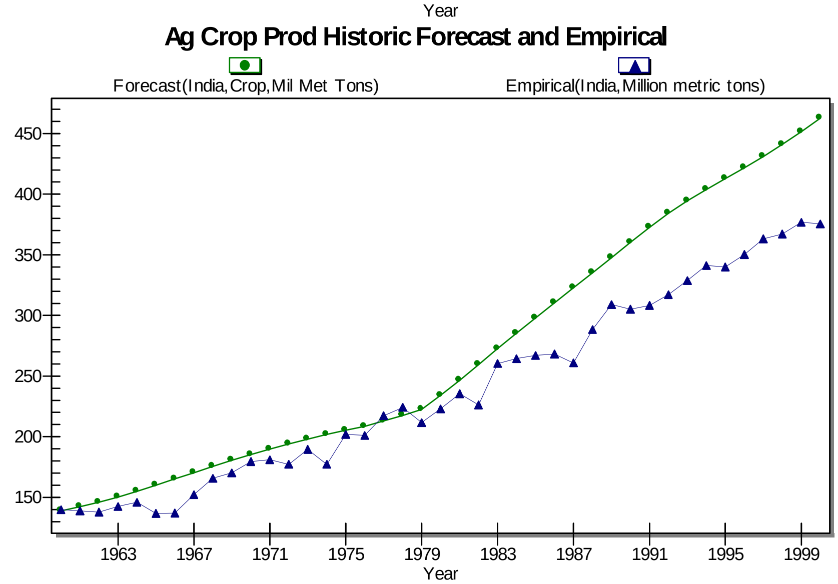
Ag Crop Prod Historic Forecast and Empirical
Forecast(World,Crop,Mil Met Tons)
Empirical(World,Million metric tons)
4000
3500
3000
2500
2000
1500
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year



Ag Crop Prod Historic Forecast and Empirical
Forecast(OECD,Crop,Mil Met Tons)
Empirical(OECD,Million metric tons)
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


Ag Crop Prod Historic Forecast and Empirical
Forecast(non-OECD,Crop,Mil Met Tons)
Empirical(non-OECD,Million metric tons)
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

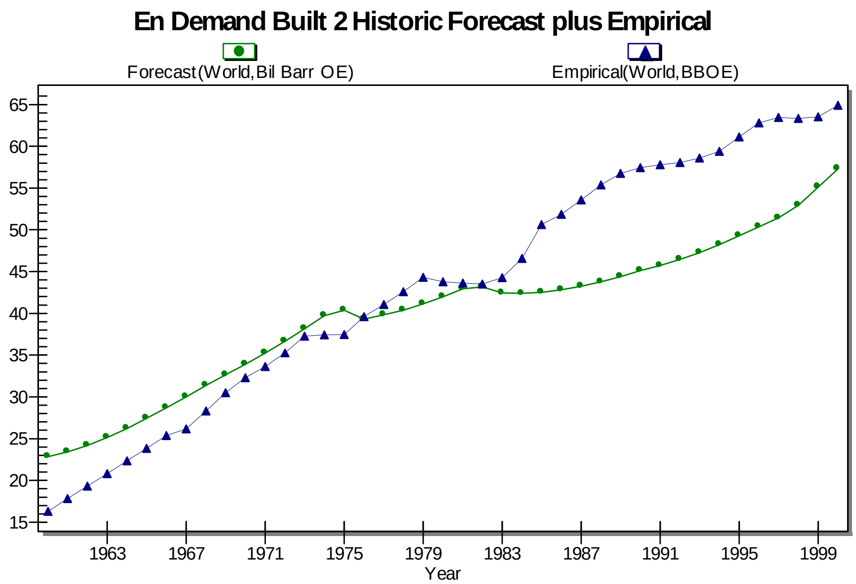

Ag Crop Prod Historic Forecast and Empirical
Forecast(China,Crop,Mil Met Tons)
Empirical(China,Million metric tons)
900
800
700
600
500
400
300
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

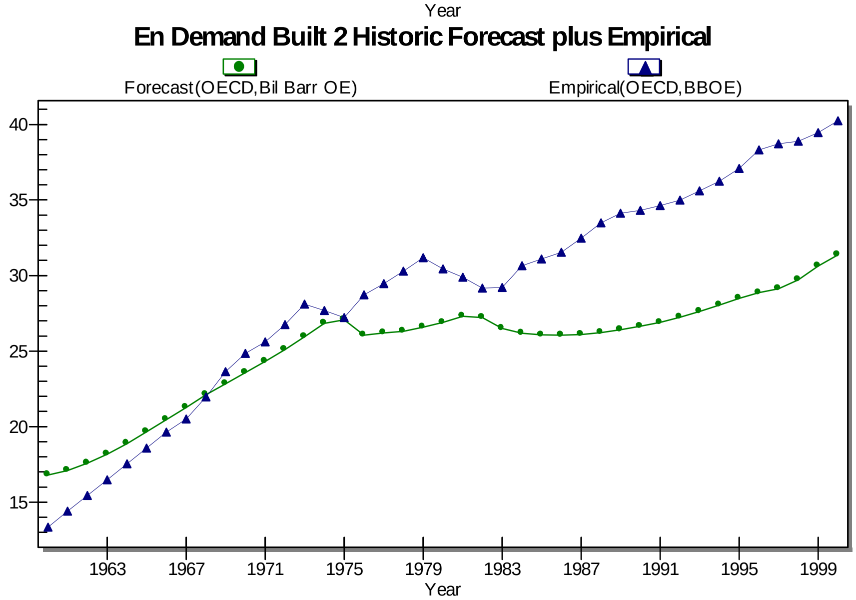

Ag Crop Prod Historic Forecast and Empirical
Forecast(India,Crop,Mil Met Tons)
Empirical(India,Million metric tons)
450
400
350
300
250
200
150
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

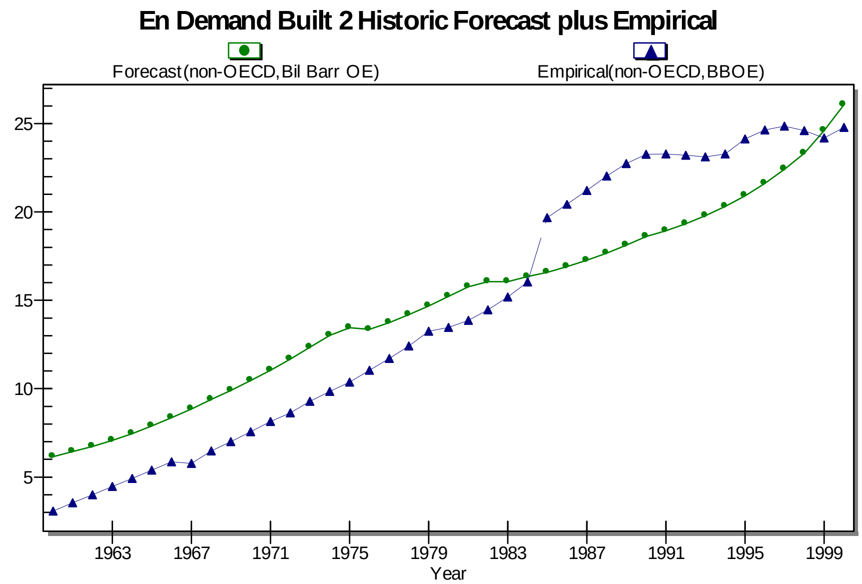
Going deeper into the drivers of the agricultural model would take us into land use patterns. Because of the importance of forest area, the environmental section will look at land use.

4.6 Energy

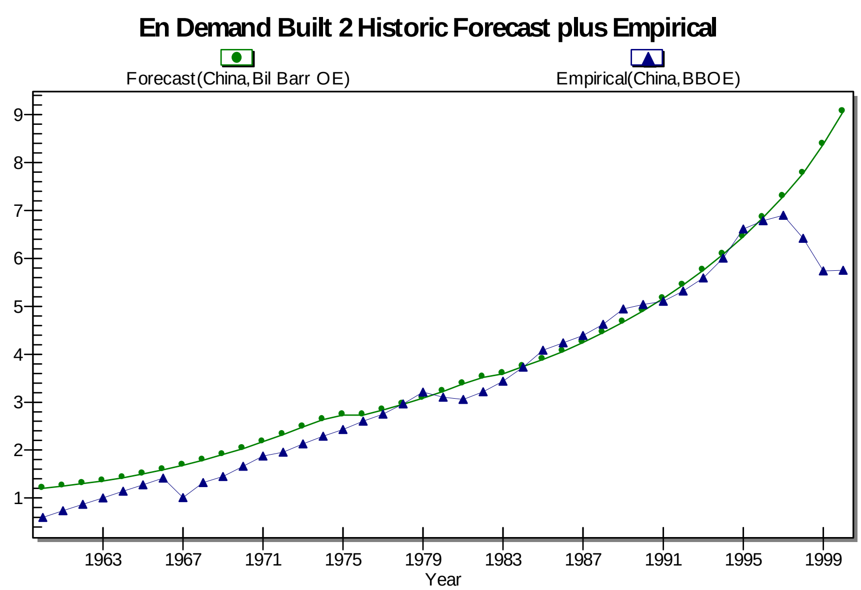
The central variable in energy, in terms of meeting human needs, is energy demand/use. One critical difficulty in exploring model behavior relative to empirical values is that energy demand/use is measured only in terms of apparent demand: production (of all energy forms) plus imports minus exports. The data for all of these elements are incomplete and irregular in quality. The five figures below show historic forecasts and empirical values once again for the World, OECD countries, non-OECD countries, China and India.

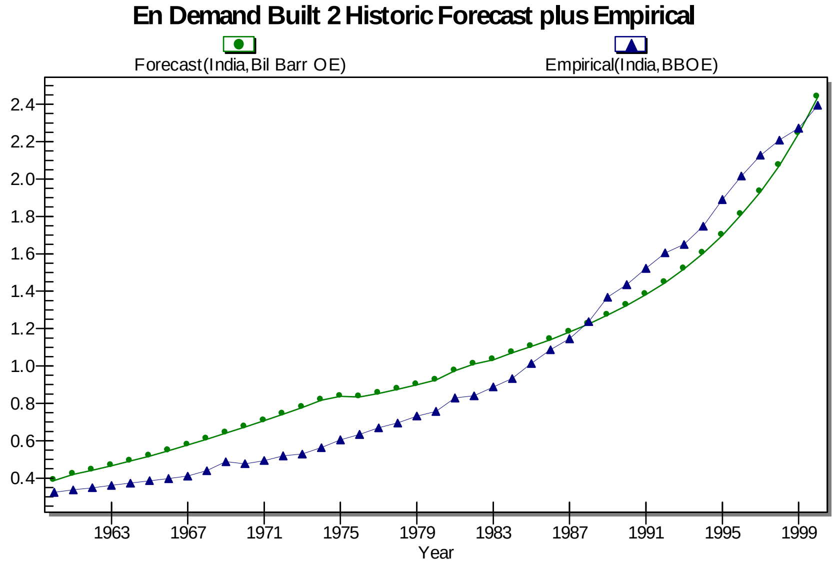






The figure below for China shows recent historic data that appear very problematic and subject to update/revision.

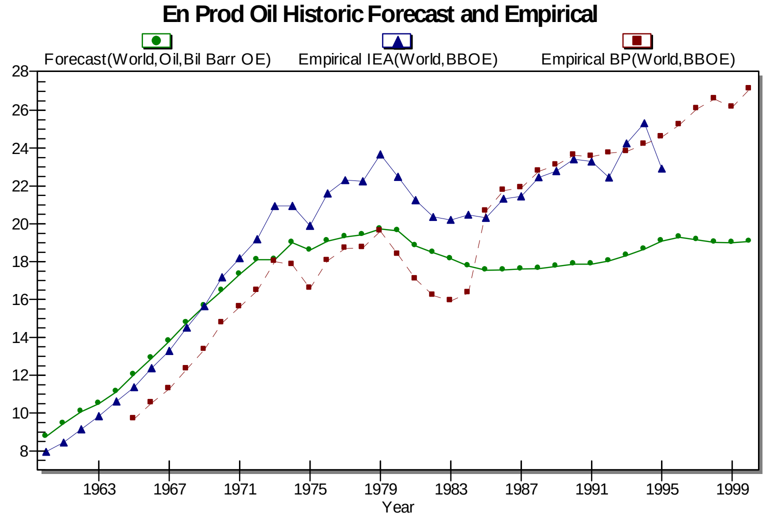


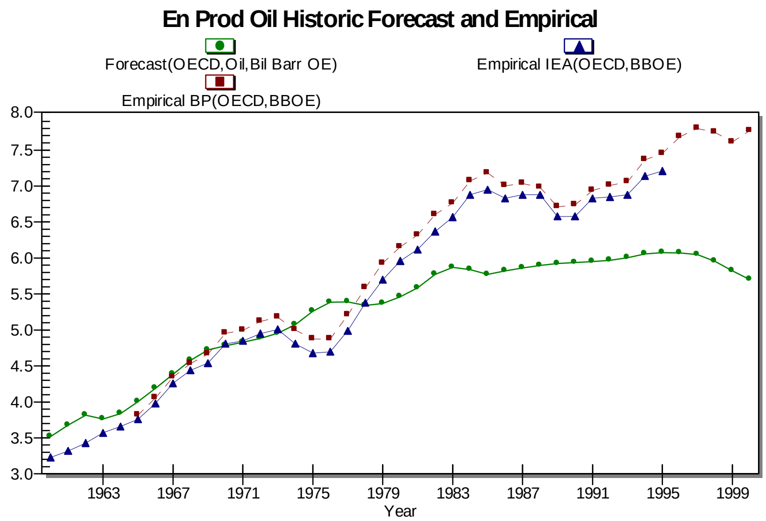


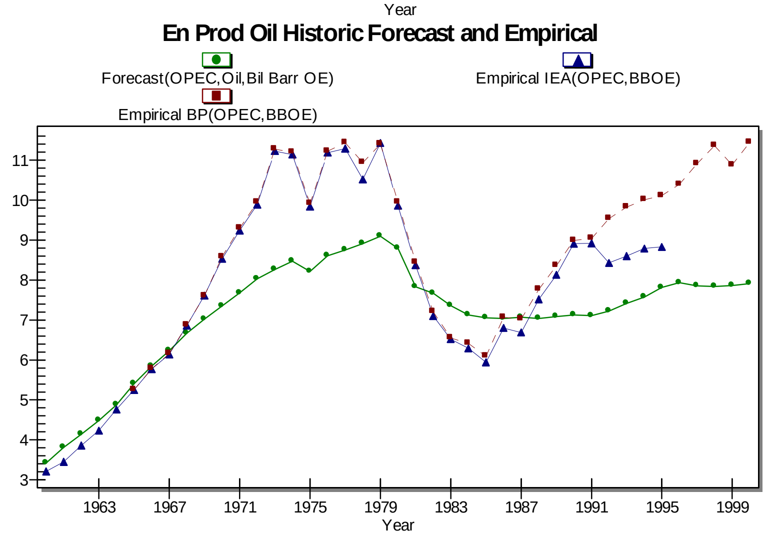
What interventions were made in the model with respect to energy demand (above)? The primary one was a global shift in demand patterns relative to the size of GDP beginning about 1980 (ENRGDPGR). In earlier years, energy demand and GDP grew largely in lockstep; thereafter, even taking into account demand responses to higher prices, energy demand tended to grow about 0.5 percent slower. Part of that decoupling was responsive, at least until the mid-1980s, to higher prices, but part also was responsive to energy policies, including taxation and other demand-side interventions. Not all countries introduced those in the same manner. Japan, with its high dependence on foreign sources, was especially reactive and it was necessary to introduce a multiplier on demand (ENDEMM) to capture its pattern of intervention [this needs to be intensified]. In contrast, the United States decided not to intervene in any significant way and a calibration parameter was set to dampen price responses [switch this to ENDEMM].

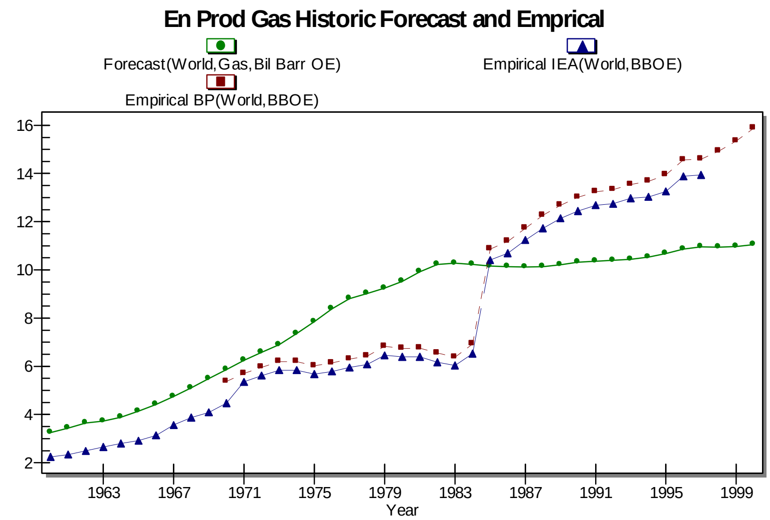
ENRGDPGR,0:25,-.5@20,-.5:100
ENDEMM,JAPAN,1,.7@20,.7:200
ELASDE,USA,-.35:25,0@15,0:100

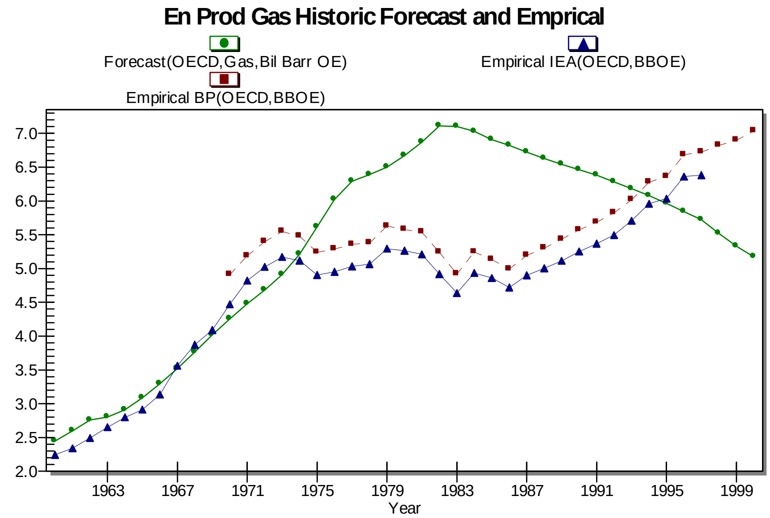
Turning to the supply side, the following graphs show production for the world, OECD countries, and, in contrast to earlier sets, the countries of the Organization of Petroleum Exporting Countries(OPEC) for oil and gas. Two empirical series are provided, one from the International Energy Agency (IEA) and one from British Petroleum. There is enough variation in their temporal and geographic coverage that having both is useful.

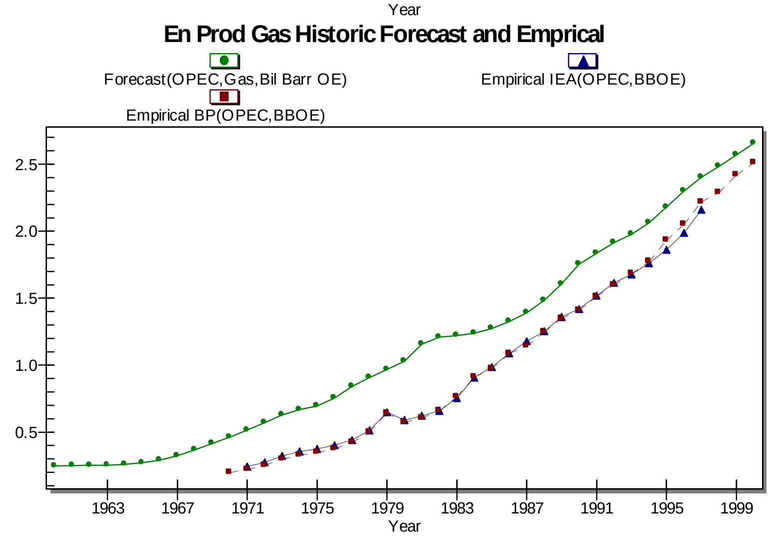

En Prod Oil Historic Forecast and Empirical
Forecast(World,Oil,Bil Barr OE)
Empirical IEA(World,BBOE)
Empirical BP(World,BBOE)
Year


En Prod Oil Historic Forecast and Empirical
Forecast(OECD,Oil,Bil Barr OE)
Empirical IEA(OECD,BBOE)
Empirical BP(OECD,BBOE)
Year


En Prod Oil Historic Forecast and Empirical
Forecast(OPEC,Oil,Bil Barr OE)
Empirical IEA(OPEC,BBOE)
Empirical BP(OPEC,BBOE)
Year







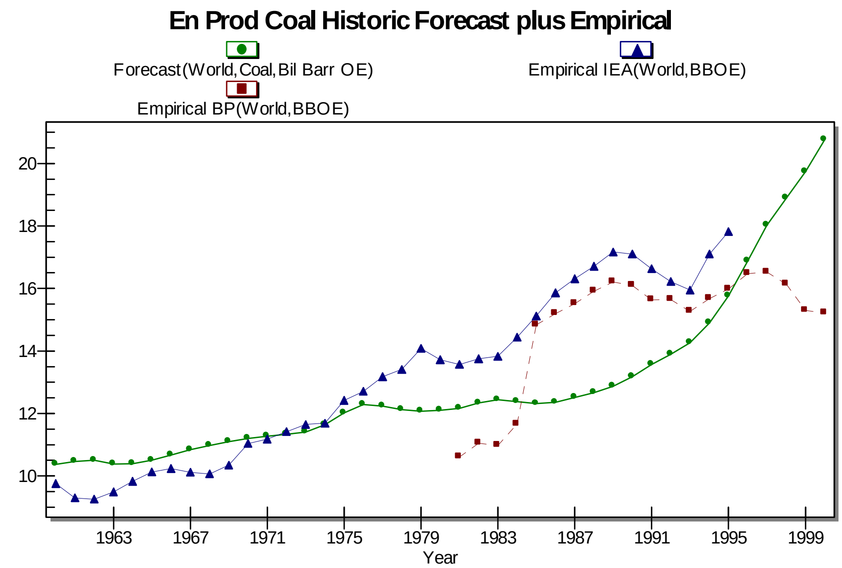
Even though the fit of historic forecast and empirical values is not especially good, a substantial number of interventions were made for improvement of historic forecasts. The most significant ones were around the oil shocks of the 1970s, both triggered by wars and political action, not just by market forces. Energy export constraints (ENXL) were put in for Venezuela, Kuwait, Saudi Arabia, Kuwait and Russia (although not an OPEC member, it tends to follow on many issues). [should presumably also have a constraint for Iran and possibly Iraq] The production growth of oil in the OPEC countries in the 1960s was, however, also extraordinary and helped set up the shocks; it proved necessary to put a multiplier on that pattern in order to begin to approximate it. In addition, an additive cartel-based price premium (ENCARTPP) was added for the years of the oil shocks.

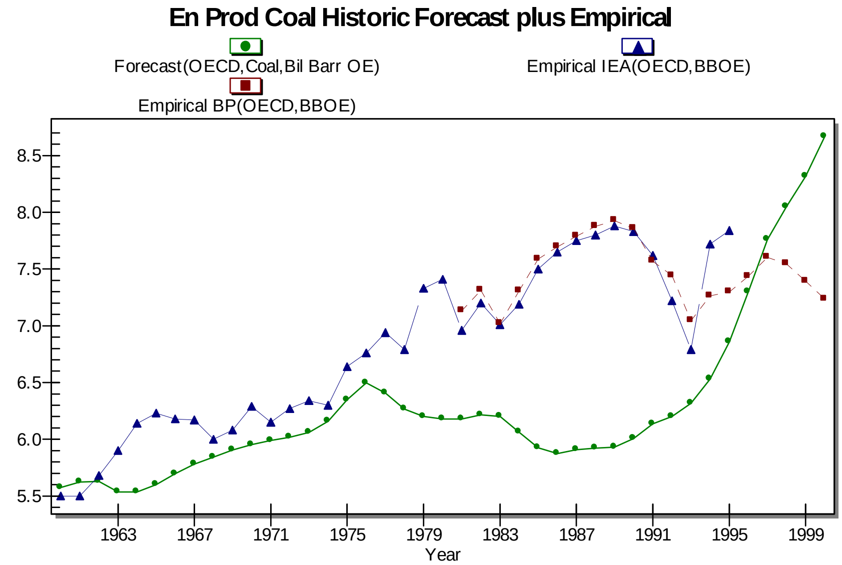
ENXL,Venezuela,0:13, .8:100
ENXL,Kuwait,1:13,.5@3, 1:4,.4:3,1:8,.1:2, 1:100
ENXL,Saudi Arabia,3:13,2.5:2,3:100
ENXL,Russia,0:13,2.5:100
ENPM,OPEC,Oil,1,3@12,3:8,1:8,2@16,2:100
ENPRR,Kuwait,1,.06:100
ENCARTPP,0:13,100:7,200:3,0:100

It was not just OPEC oil exporters, however, that intervened in markets. Therefore the following interventions were also made. Oil production was given additional impetus in most areas of the world outside of OPEC via various assists to technological advance in production (ETECHADV). At the same time, various environmental constraints on hydroelectric power were raising rather than lowering its cost of production. A number of countries, including the US, the UK, the Netherlands, and Norway increased their rates of discovery of oil or gas (RDM). North Sea oil, very expensive relative to that in the Middle East, came into production much more quickly (EPRODR) than it would have without high prices from OPEC.

ETECHADV,OIL,.008:120
ETECHADV,Hydro,-.01:120
RDM,USA,1,1.3:100
RDM,Unitd Kingdm,1,2:100
RDM,Netherlands,2,.3:100
RDM,Norway,1,2:100
EPRODR,Unitd Kingdm,1,.5:100
EPRODR,Norway,1,.5:100

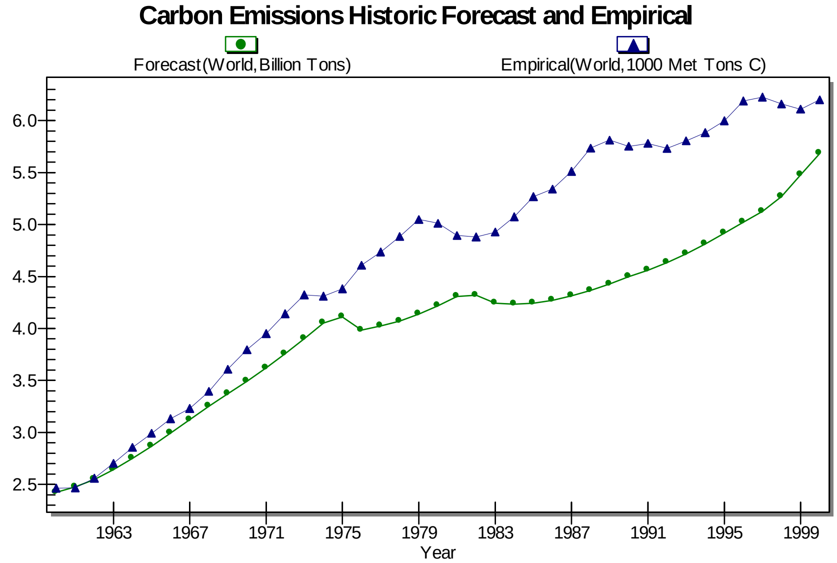
The two graphs below complete the picture of production across the major fossil fuels (oil, gas, and coal).



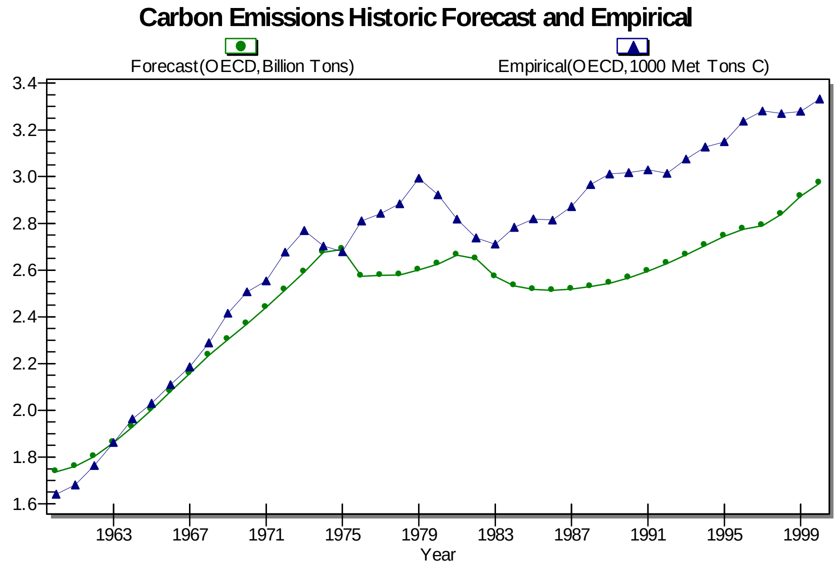


4.7 Environment

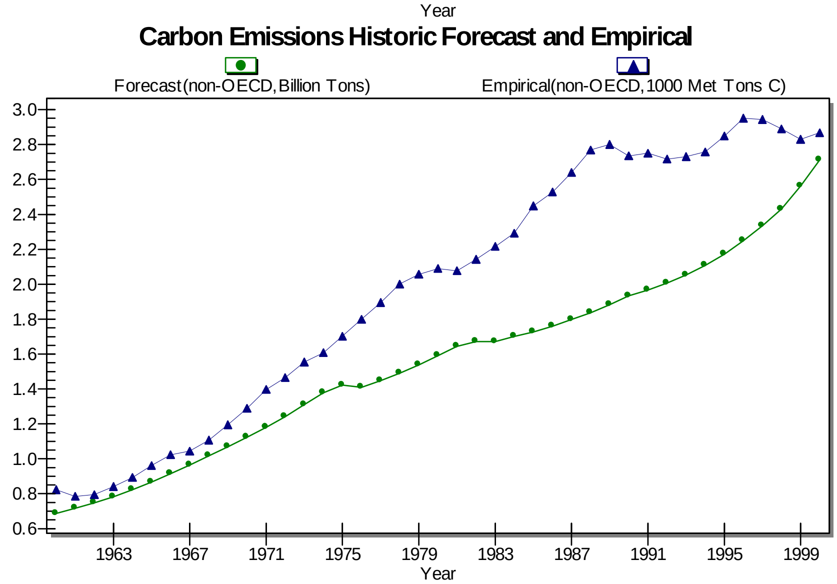
The two environmental issues examined here are carbon emissions and land use. With respect to annual carbon emissions, the five figures below once again show historic forecasts and empirical values for the world, OECD countries, non-OECD countries, China and India. No calibrating interventions were made directly in this part of the model; the interventions in the energy module already described above obviously do affect carbon emissions.



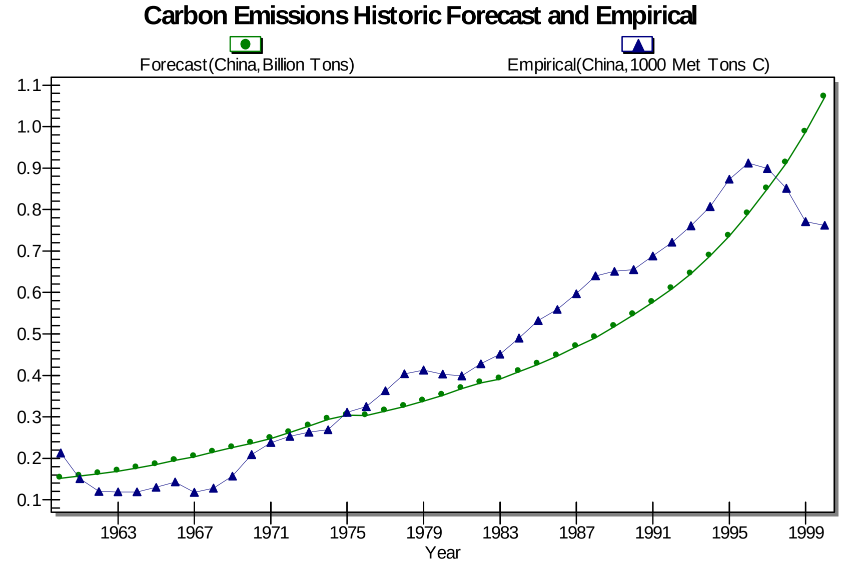
Carbon Emissions Historic Forecast and Empirical
Forecast(World, Billion Tons)
Empirical(World, 1000 Met Tons C)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

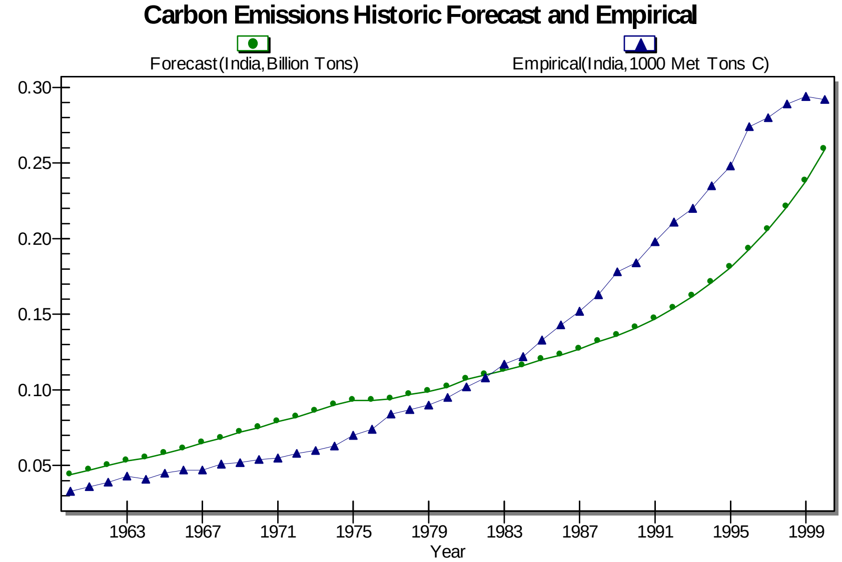


Carbon Emissions Historic Forecast and Empirical
Forecast(OECD, Billion Tons)
Empirical(OECD, 1000 Met Tons C)
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year



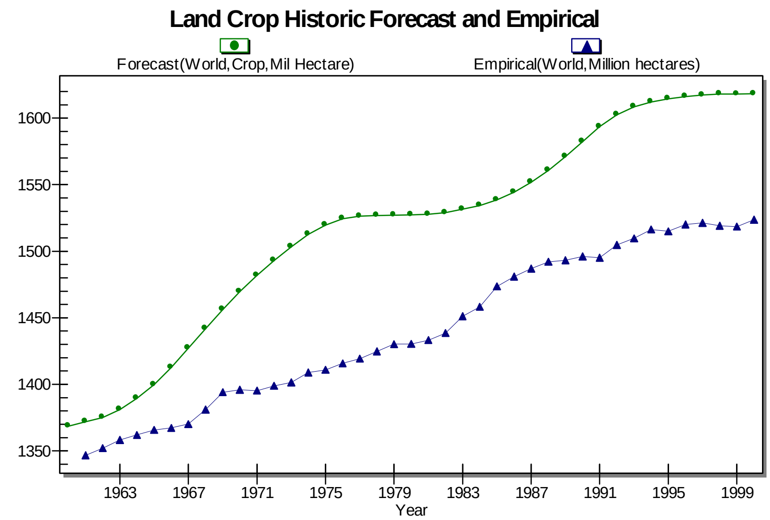
Carbon Emissions Historic Forecast and Empirical
Forecast(non-OECD, Billion Tons)
Empirical(non-OECD, 1000 Met Tons C)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year



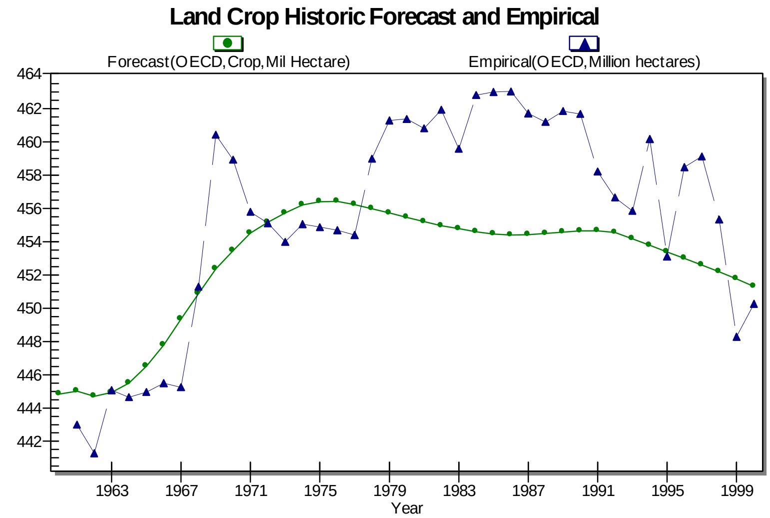


Turning to land use, the five figures below show historical forecasts and empirical values once again for the world, OECD countries, non-OECD countries, China and India. Again, there were no calibrating interventions made in this part of the model. The data appear to have major weaknesses for China. In the case of India, the historic forecast and empirical values diverge, but it is important to look at the scale: essentially both are showing very little change over the 40-year period.

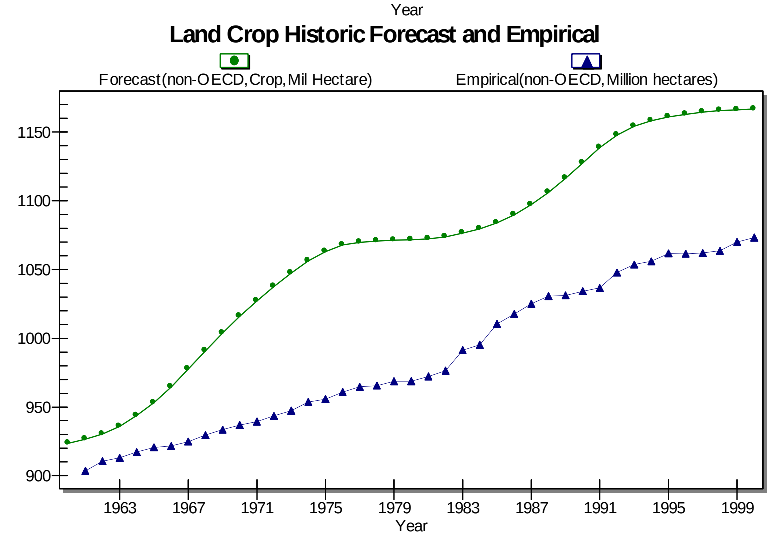
More generally, some of the figures below suggest more substantial discrepancies between historic forecasts and empirical values than in other areas of the model. One reason for this is likely the highly politicized character of land use; for instance, OECD countries tend to subsidize their crop areas, leading perhaps to the cultivation of somewhat more crop land in those countries than the model anticipated and also less than expected land under crops in the non-OECD countries.



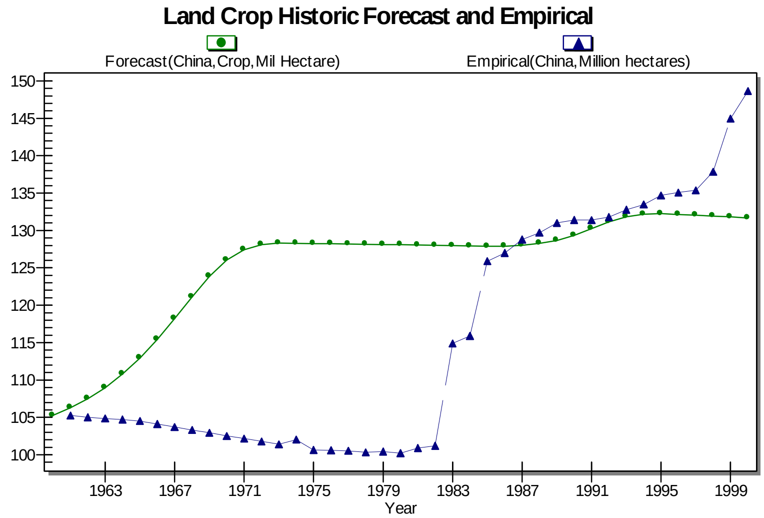
Land Crop Historic Forecast and Empirical
Forecast(World,Crop,Mil Hectare)
Empirical(World,Million hectares)
1600
1550
1500
1450
1400
1350
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

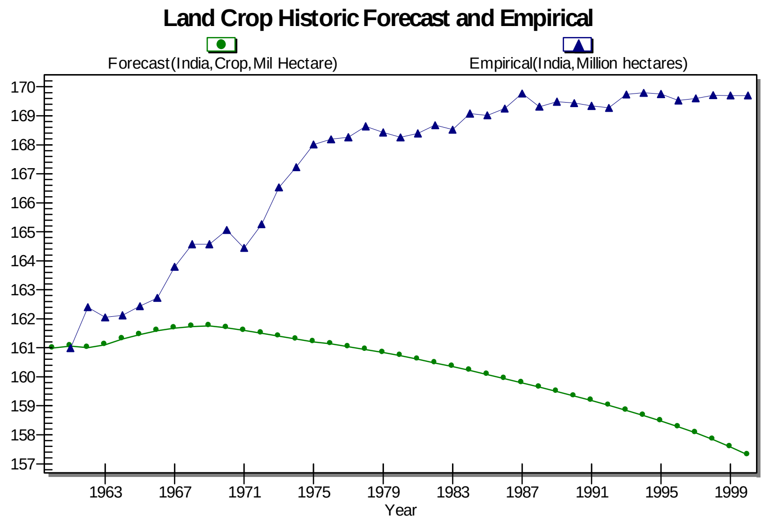


Land Crop Historic Forecast and Empirical
Forecast(OECD,Crop,Mil Hectare)
Empirical(OECD,Million hectares)
464
462
460
458
456
454
452
450
448
446
444
442
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

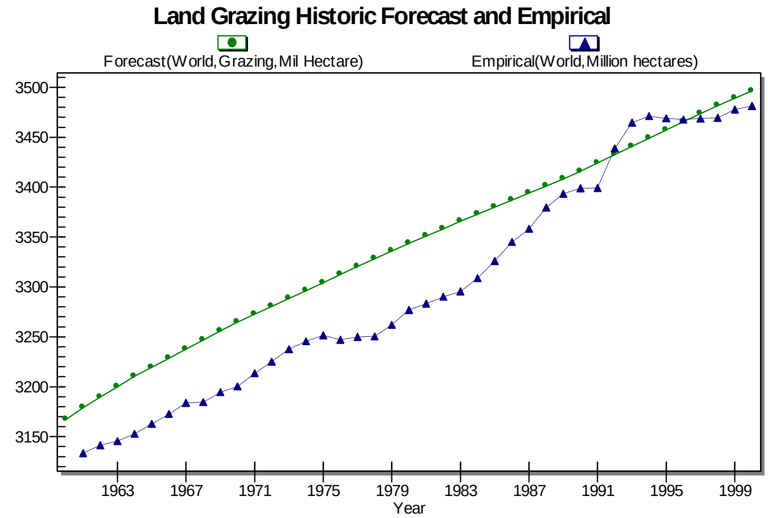


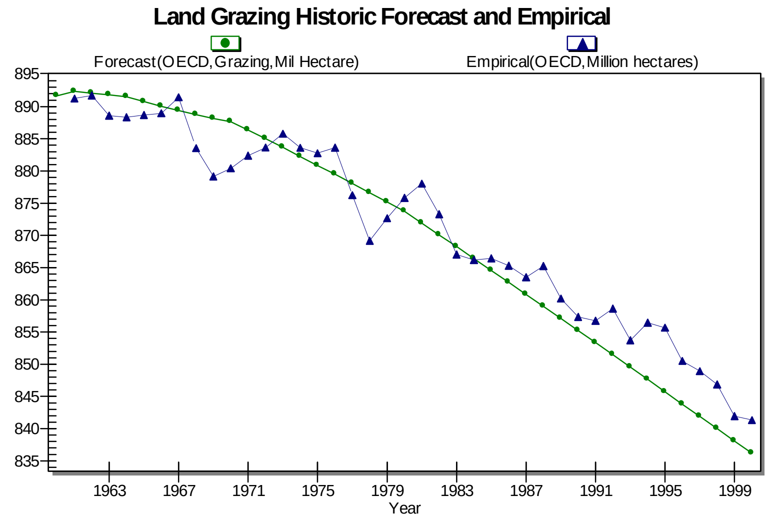
Land Crop Historic Forecast and Empirical
Forecast(non-OECD,Crop,Mil Hectare)
Empirical(non-OECD,Million hectares)
1150
1100
1050
1000
950
900
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

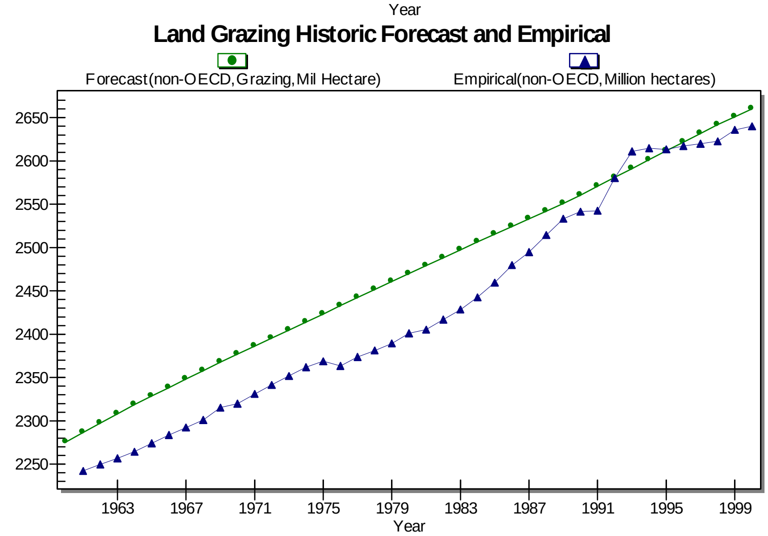


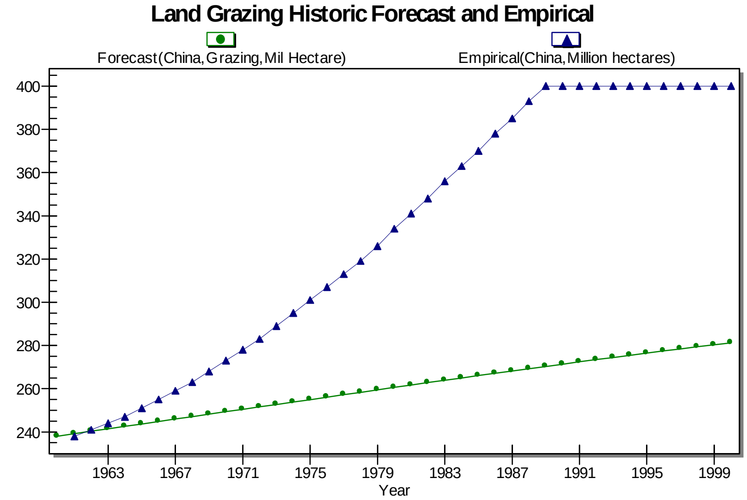


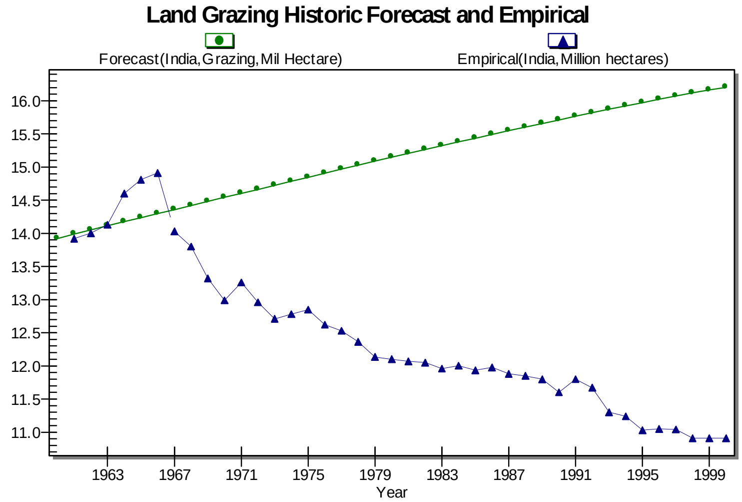
Shifting to grazing land, the figure below show values for the world, OECD countries, non-OECD countries, China and India. Once again, the data for China appear questionable. And the seeming divergence in India is not so substantial when one considers (1) the scale, which indicates modest change over time (2) cultural values with respect to cattle production and the very limited area given to grazing generally within India. China also has very limited land set aside for grazing given its geographic and population size.


Land Grazing Historic Forecast and Empirical
Forecast(World,Grazing,Mil Hectare)
Empirical(World,Million hectares)
3500
3450
3400
3350
3300
3250
3200
3150
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

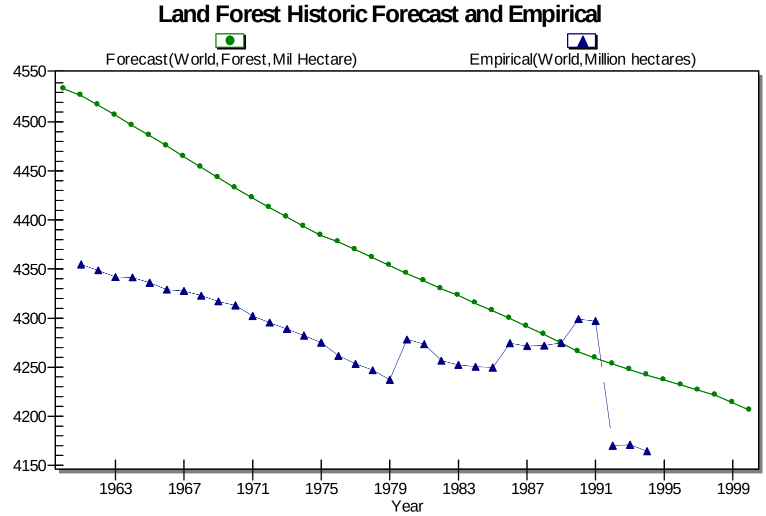

Land Grazing Historic Forecast and Empirical
Forecast(OECD,Grazing,Mil Hectare)
Empirical(OECD,Million hectares)
895
890
885
880
875
870
865
860
855
850
845
840
835
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

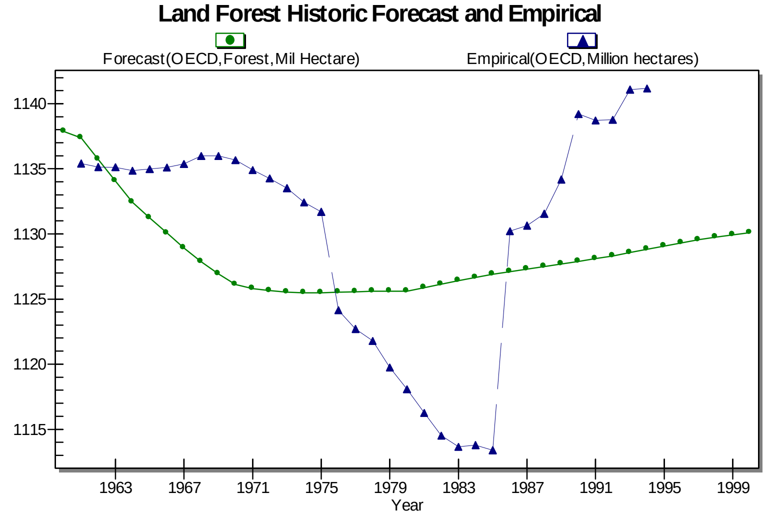

Land Grazing Historic Forecast and Empirical
Forecast(non-OECD,Grazing,Mil Hectare)
Empirical(non-OECD,Million hectares)
2650
2600
2550
2500
2450
2400
2350
2300
2250
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

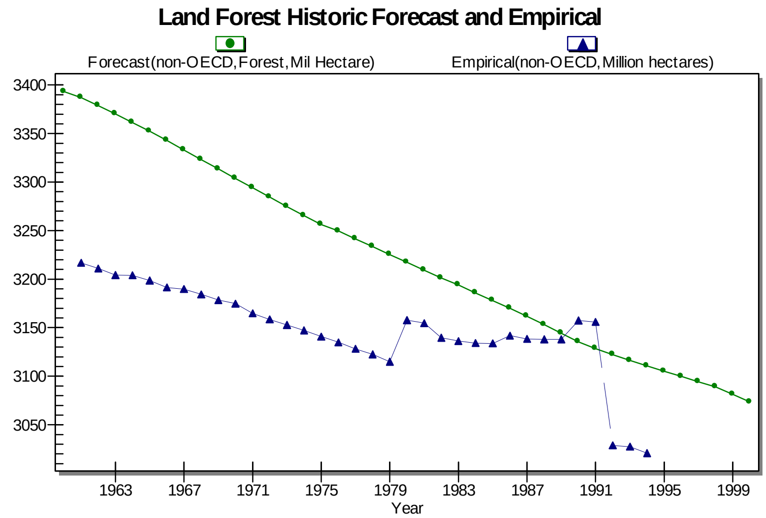


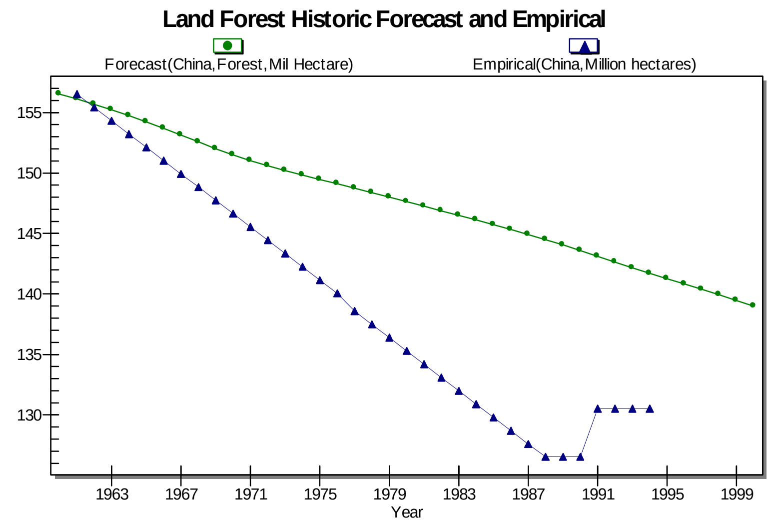


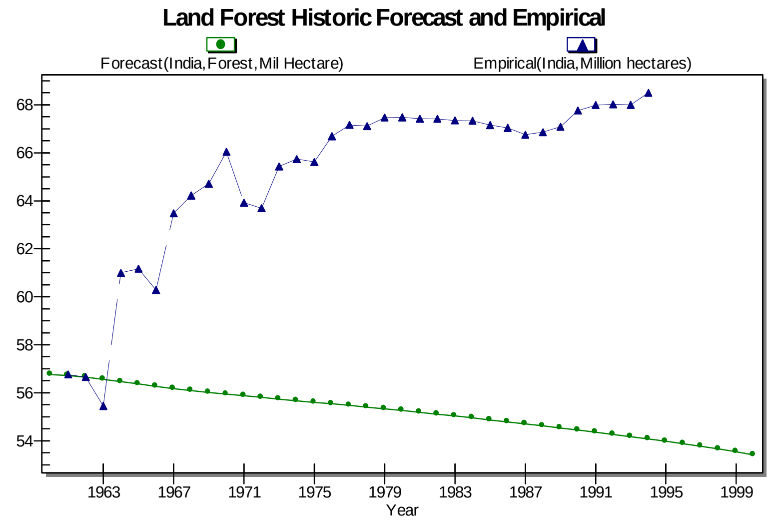
Turning to forest, the five graphs below again show the world, OECD countries, non-OECD countries, China and India. One of the interesting features is the apparent reversal of deforestation for non-OECD countries in both data and historical forecast. Once again the fit for India appears worse than it is, given the small change in forest area from 1960 through 2000 – and it is somewhat difficult to believe that the forest area of India actually increased during that period as the data suggest.


Land Forest Historic Forecast and Empirical
Forecast(World,Forest,Mil Hectare)
Empirical(World,Million hectares)
4550
4500
4450
4400
4350
4300
4250
4200
4150
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

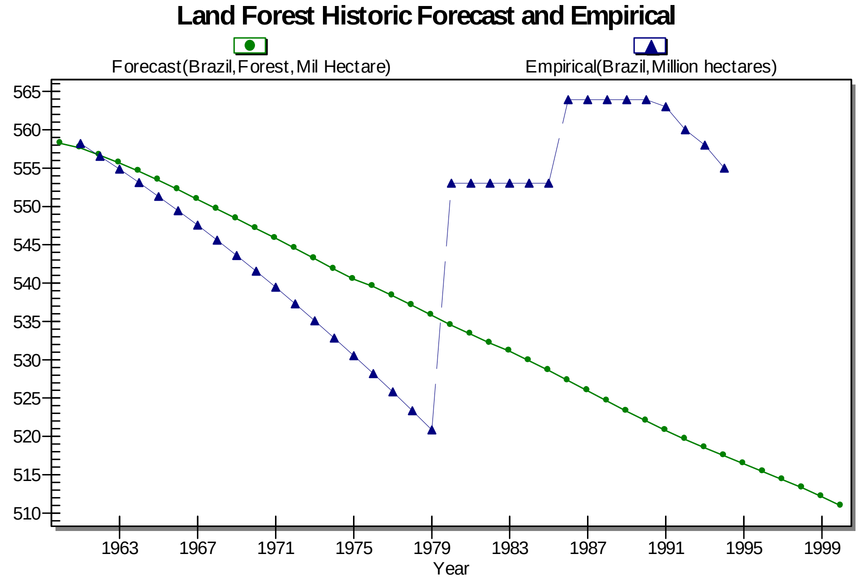

Land Forest Historic Forecast and Empirical
Forecast(OECD,Forest,Mil Hectare)
Empirical(OECD,Million hectares)
1140
1135
1130
1125
1120
1115
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


Land Forest Historic Forecast and Empirical
Forecast(non-OECD,Forest,Mil Hectare)
Empirical(non-OECD,Million hectares)
3400
3350
3300
3250
3200
3150
3100
3050
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year





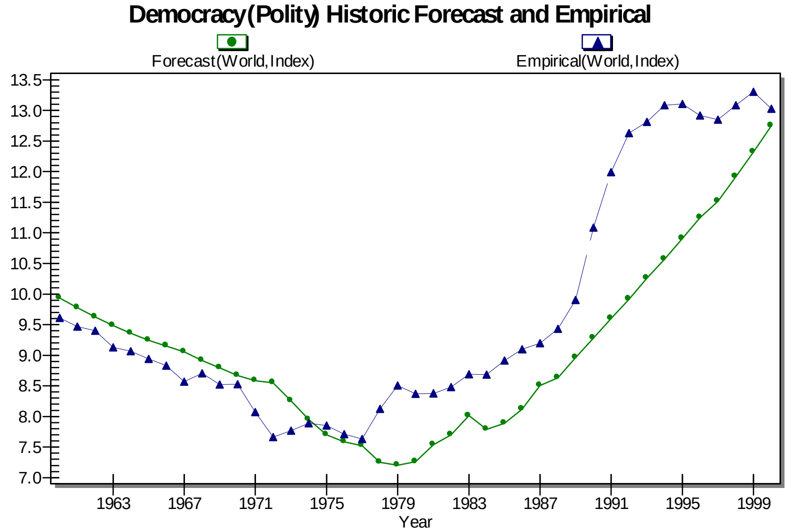
Of all the comparisons made in this paper between historical forecasts and data, land use is one of the most difficult, in part because of the poor quality of data on it. Note, for example, the figure below, representing forest area in Brazil. Clearly the historic data are bad and the historic forecast looks like it might be quite reasonable.

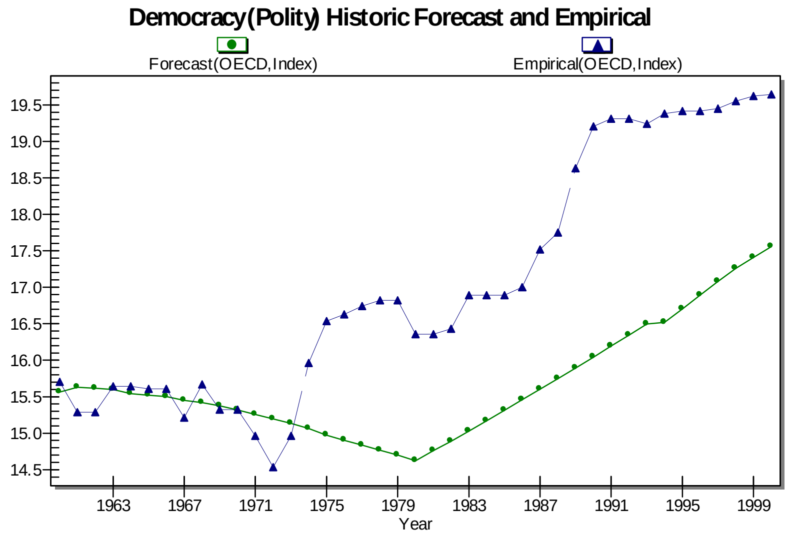


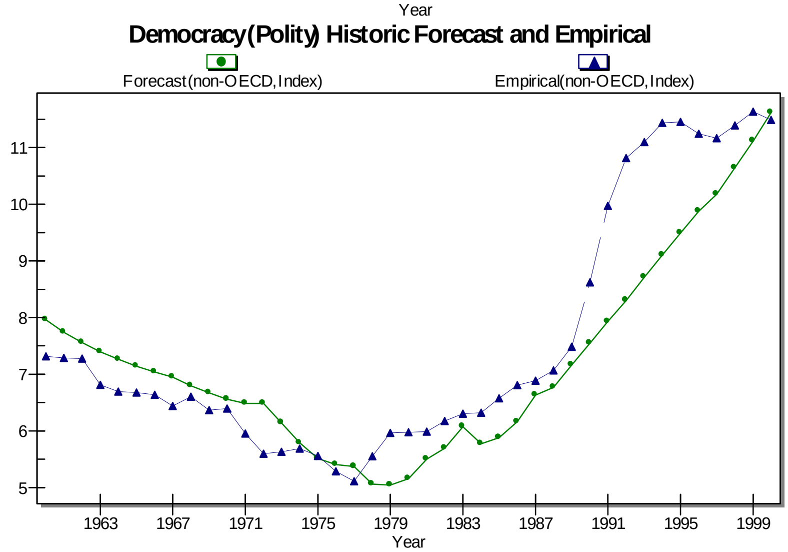
4.8 Socio-Political: Organization and Governance

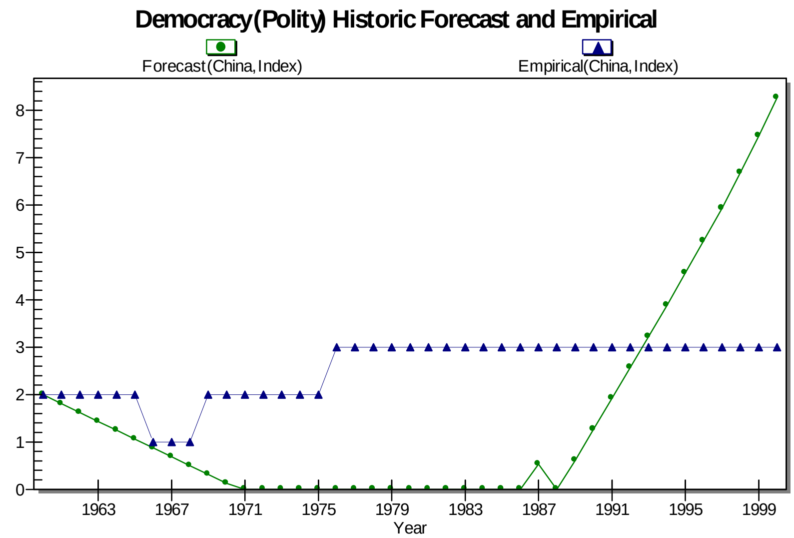
The discussion of socio-political change is broken here into three subsections. The first looks at society-wide issues of organization and governance. The next will turn to government spending. The third and final subsection will look at human outcomes (such as education levels).

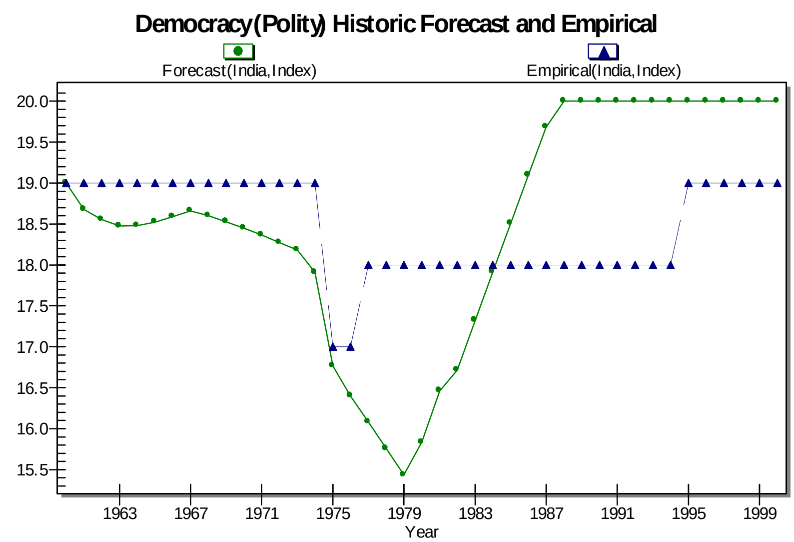
With respect to society-wide organization and governance, the first set of five graphs looks at democracy, historic forecasts and empirical values. The fits are quite good, in the absence of parametric calibration and intervention. That is deceiving, however, because the model code has hard-wired a “democratic wave” into this historic period that has a period of 20 years of downturn before a new upturn (building on the study of democratic waves by scholars such as Huntington 1991). Interestingly, that downturn of the second democratic wave even captures the Indian Emergency period (1975-77).


Democracy(Polity) Historic Forecast and Empirical
Forecast(World,Index)
Empirical(World,Index)
Year

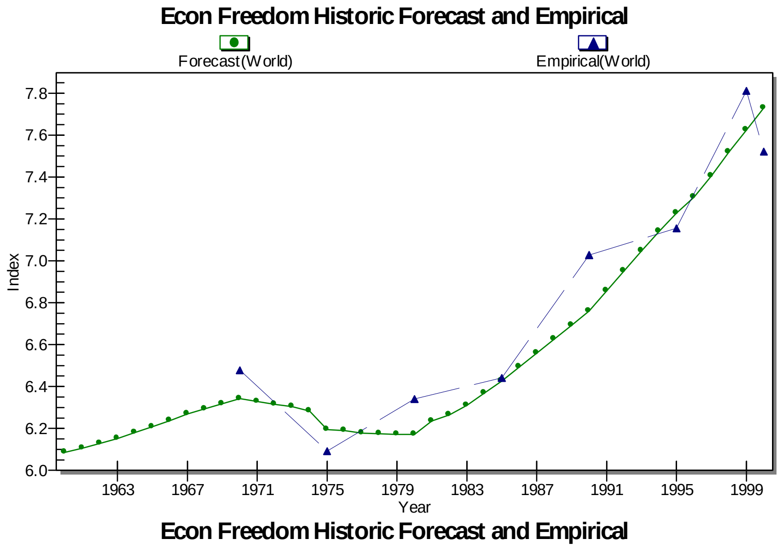

Democracy(Polity) Historic Forecast and Empirical
Forecast(OECD,Index)
Empirical(OECD,Index)
Year

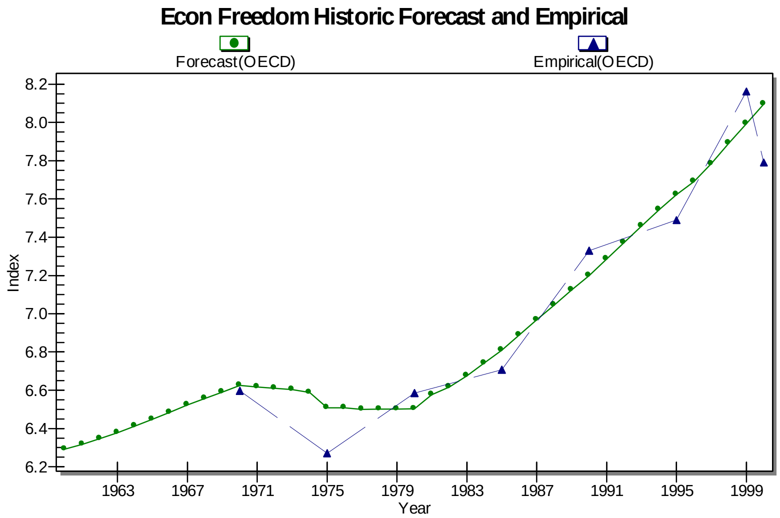

Democracy(Polity) Historic Forecast and Empirical
Forecast(non-OECD,Index)
Empirical(non-OECD,Index)
Year

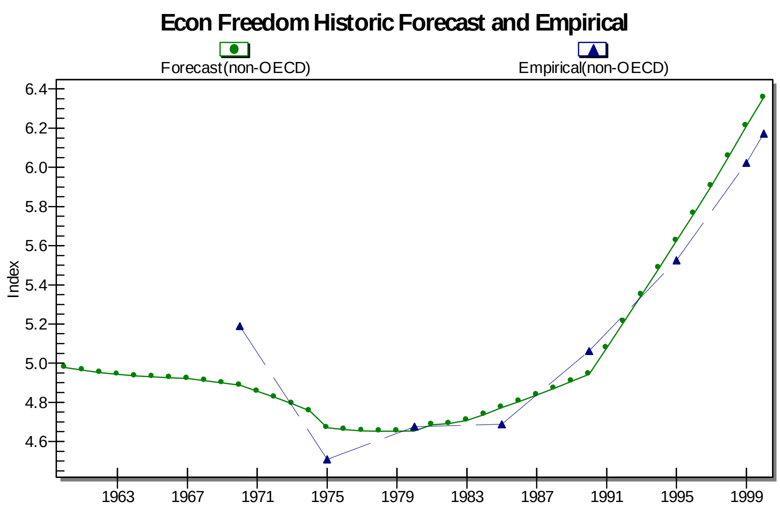


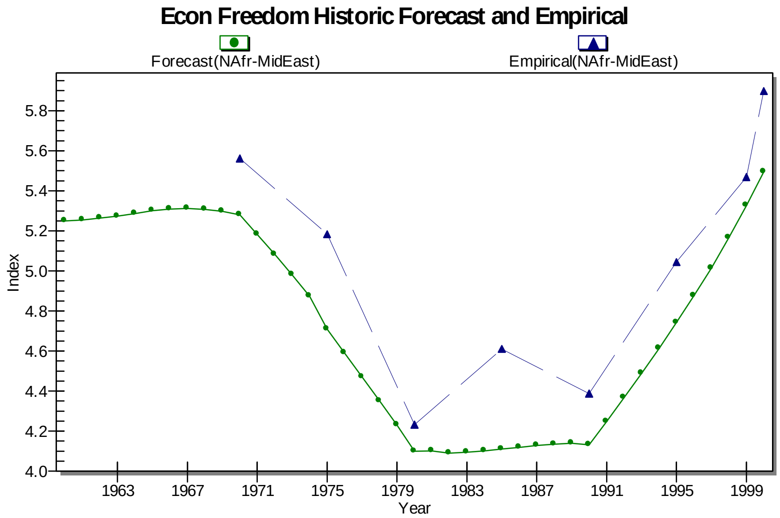


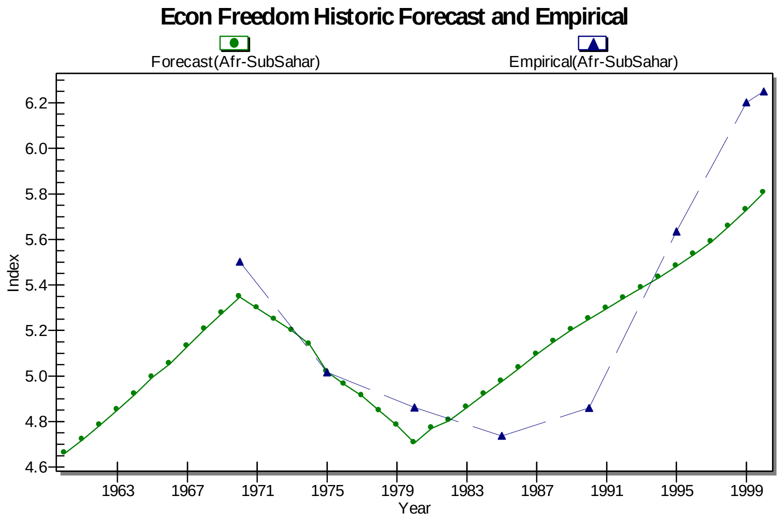
Moving from political freedom to economic freedom, the following graphs still again display historic forecasts and empirical data for the world, OECD countries, non-OECD countries, China and India. In this case, however, graphs are added for North Africa and the Middle East for Sub-Saharan Africa, and for the Transition Economies. The fits are good but that is significantly because of the substantial interventions that were undertaken on this variable and detailed when the economic forecasts were discussed earlier. Such highly politicized variables are nearly impossible to forecast (in the forecasts of IFs beyond 2000 a basic relationship with GDP per capita at PPP is used, but forecasts posit varied patterns for economic freedom across the century, depending on values of a multiplier on it).

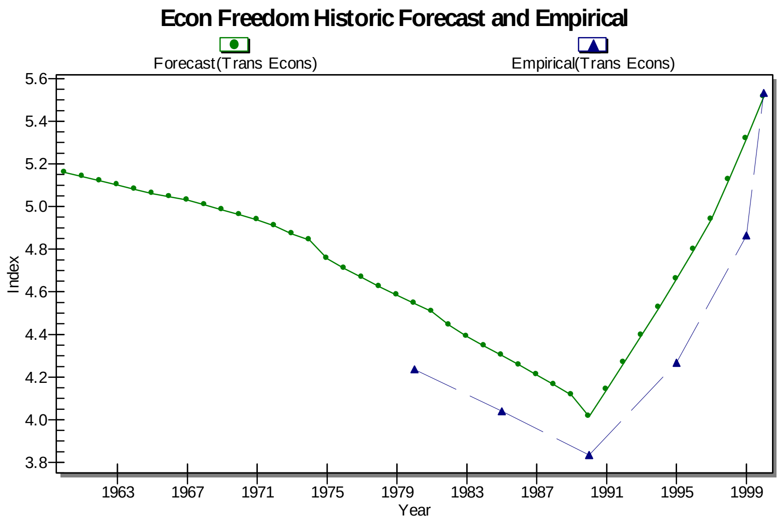

Econ Freedom Historic Forecast and Empirical
Forecast(World)
Empirical(World)
Index
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

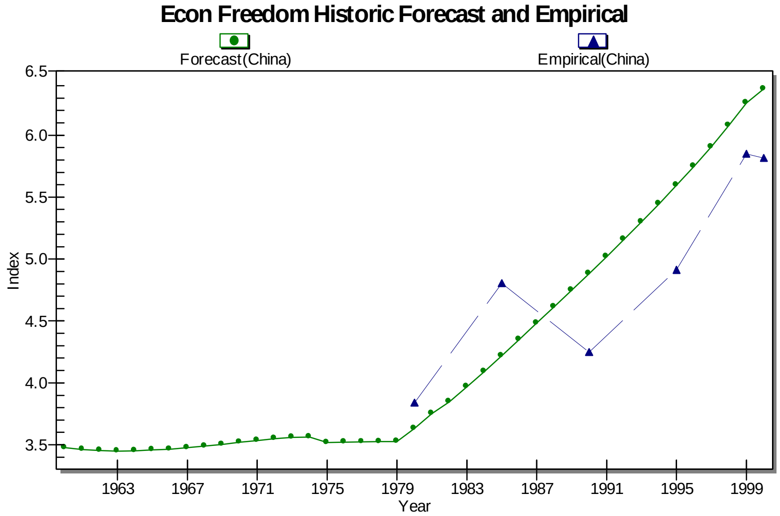

Econ Freedom Historic Forecast and Empirical
Forecast(OECD)
Empirical(OECD)
Index
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

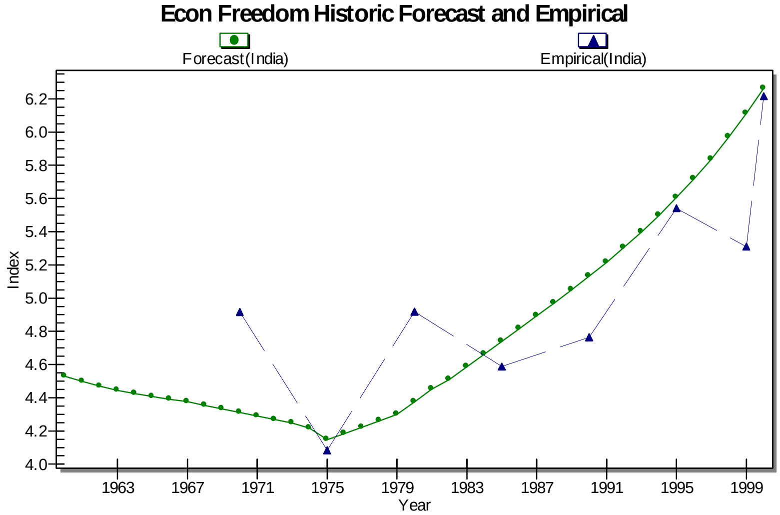

Econ Freedom Historic Forecast and Empirical
Forecast(non-OECD)
Empirical(non-OECD)
Index
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


Econ Freedom Historic Forecast and Empirical
Forecast(NAfr-MidEast)
Empirical(NAfr-MidEast)
Index
Year


Econ Freedom Historic Forecast and Empirical
Forecast(Afr-SubSahar)
Empirical(Afr-SubSahar)
Index
Year


Econ Freedom Historic Forecast and Empirical
Forecast(Trans Econs)
Empirical(Trans Econs)
Index
Year





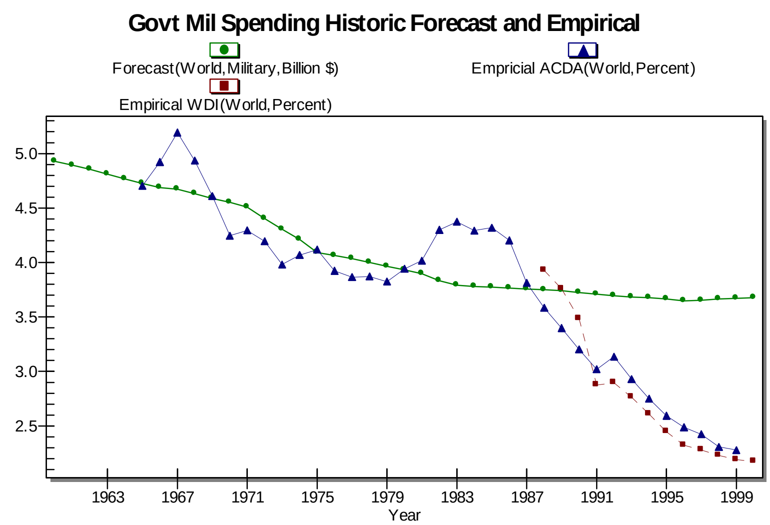
4.9 Socio-Political: Government Spending

Governmental spending is important because it affects so many other variables in the model (including education, life expectancy, and economic productivity). Although basic cross-sectionally estimated relationships with GDP per capita at PPP do a reasonable job of forecasting changes in patterns over time, there clearly were some political earthquakes in the period between 1960 and 2000, and interventions were included to represent these (GDMS). One of the most substantial was the end of the Cold War and the significant declines in military spending in the United States, Russia, the EU, and China. There was also, however, a substantial increase in military spending in Sub-Saharan Africa in the 1970s and 1980s, reflecting a combination of forces, including post-independence interstate politics and the proxy-politics of the superpowers.

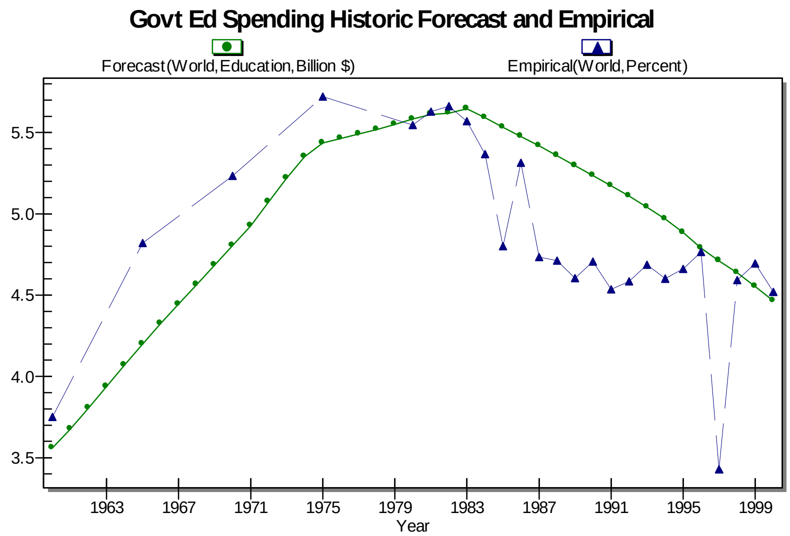
A second earthquake, much less well known was the major increase in education spending as a portion of GDP, especially in the developing world, and even more significantly in both China and India. There was an increase also in the OECD countries, but it tended to coincide with the peak of the Cold War and spending rates retreated significantly after that period ended. Although no particular data of the IFs database exist to support it, an intervention was also added increasing R&D spending in China. All of the interventions with respect to governmental spending are shown below.

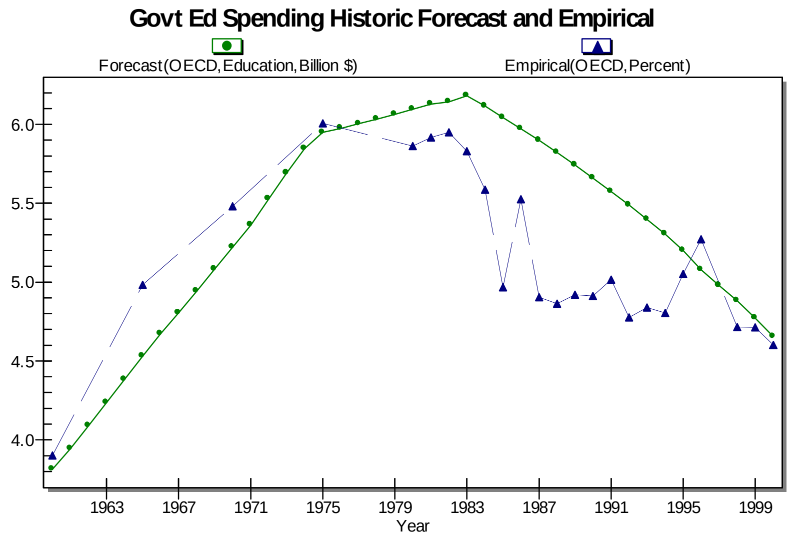
GDSM,USA,1,1,.5@40,.5:100 Military
GDSM,Russia,1,1,1@25,.4@15,.4:100
GDSM,Afr-SubSahar,1,1,1@10,1.8@10,1.7@10,1@10,1:100
GDSM,EU15,1,1,1@7,.5@33,.5:100
GDSM,China,1,1,1@9,2@3,.5@20,.3@9,.3:100
GDSM,OECD,3,1,1.8@15,1.8:8,1@17,1:100
GDSM,non-OECD,3,1,1.4@20,1.4:100 Education
GDSM,China,3,1,1@10,2.2@10,1.7@20,1.7:100
GDSM,India,3,1,2.5@40,2.5:100
GDSM,China,4,1,1.5@20,3@40,3:100 RandD; speculative without data to support

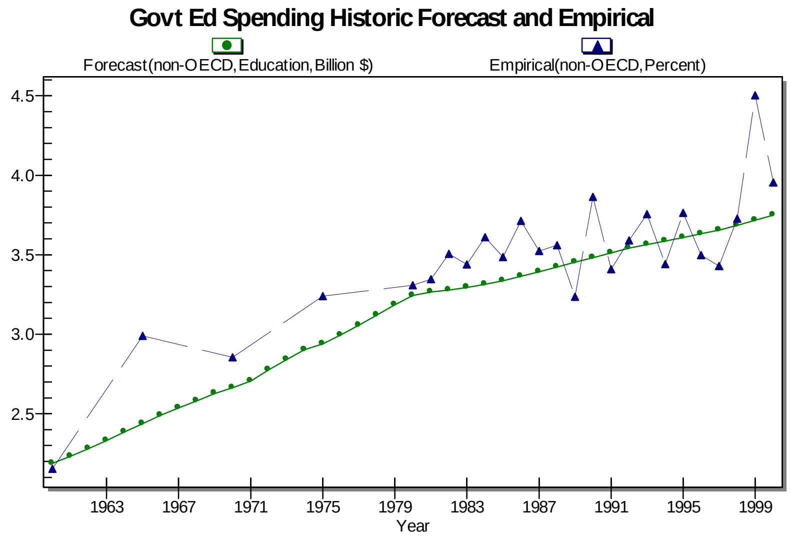
The graph immediately below shows the historic forecast and the empirical values for military spending, as a percentage of GDP, at the global level.

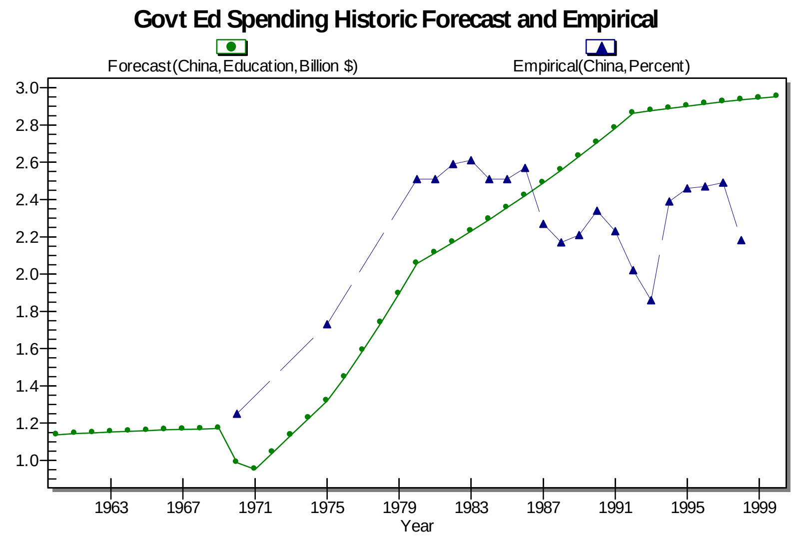


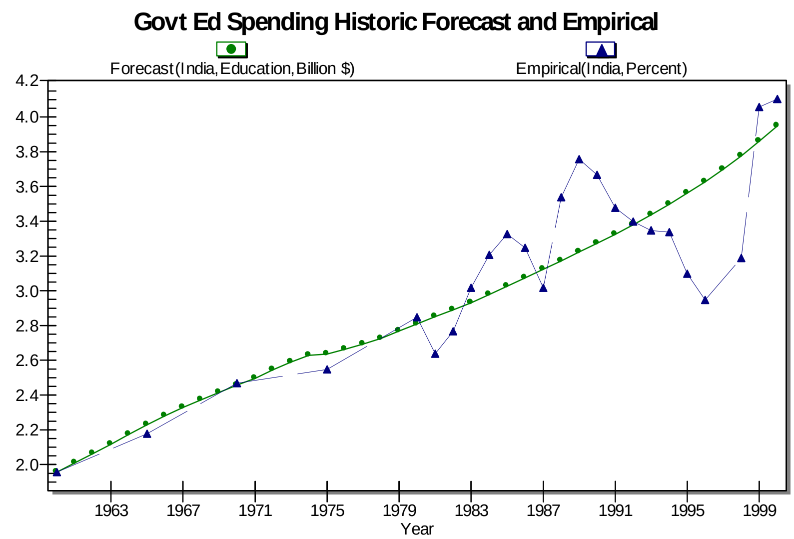
The five graphs below show historic forecasts and empirical values for education spending as a portion of GDP for the world, OECD countries, non-OECD countries, China and India.


Govt Ed Spending Historic Forecast and Empirical
Forecast(World,Education,Billion $)
Empirical(World,Percent)
5.5
5.0
4.5
4.0
3.5
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


Govt Ed Spending Historic Forecast and Empirical
Forecast(OECD,Education,Billion $)
Empirical(OECD,Percent)
6.0
5.5
5.0
4.5
4.0
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year


Govt Ed Spending Historic Forecast and Empirical
Forecast(non-OECD,Education,Billion $)
Empirical(non-OECD,Percent)
4.5
4.0
3.5
3.0
2.5
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
Year

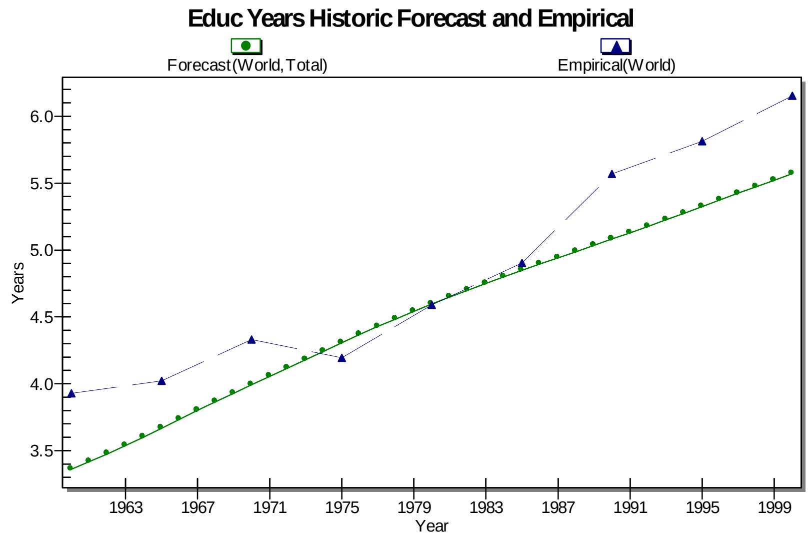


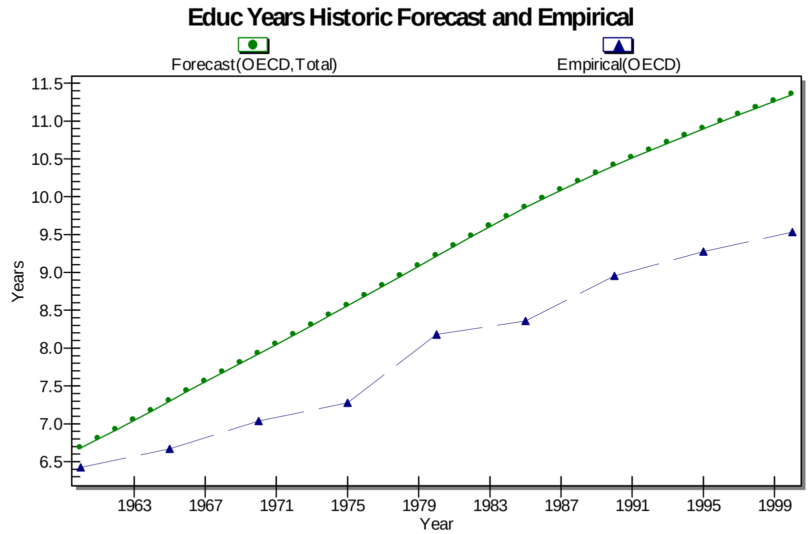


4.10 Socio-Political: Human Condition

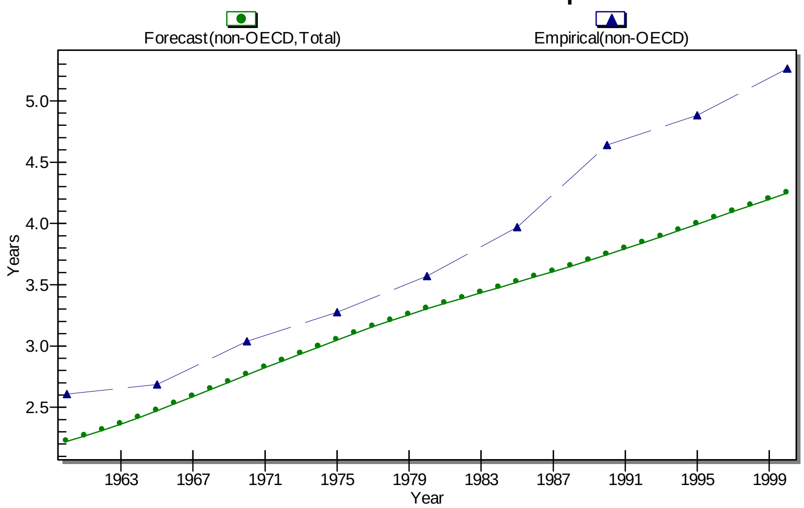
The third aspect of socio-political change moves beyond organization and governance and beyond government spending to human outcomes. We will look in turn at education years attained by the population, at literacy rates, at the human development index (HDI) and at rates of absolute poverty. Life expectancy and GDP per capita, additional critical components of human well-being, were considered earlier. In the area of human outcomes no interventions were made in the historical run other than those described above for other areas of the model.

A central measure of educational conditions is the number of years of education achieved by the average member of society 25-years old or older. Primary education can rise rapidly, but it takes generations for increased education to percolate across the entire age structure of a population. The five graphs below show the historic forecast and empirical values for that variable across the now-standard set of geographic entities. There are some initialization issues for China and other non-OECD countries for which data are not available in 1960, but the rapid growth of average years of education around the world is evident.

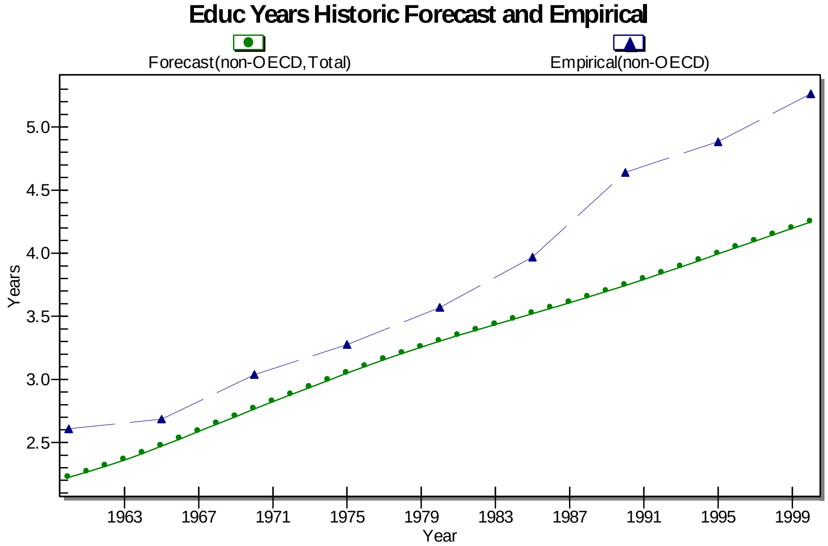




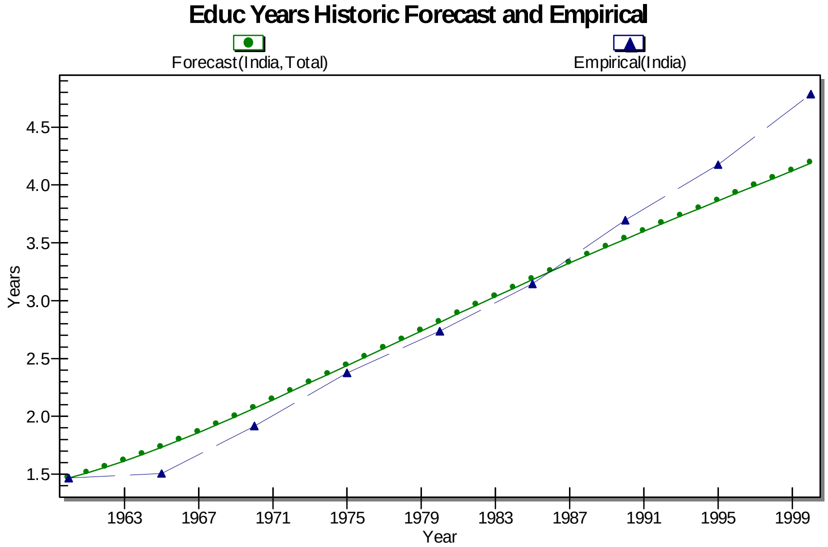
Educ Years Historic Forecast and Empirical



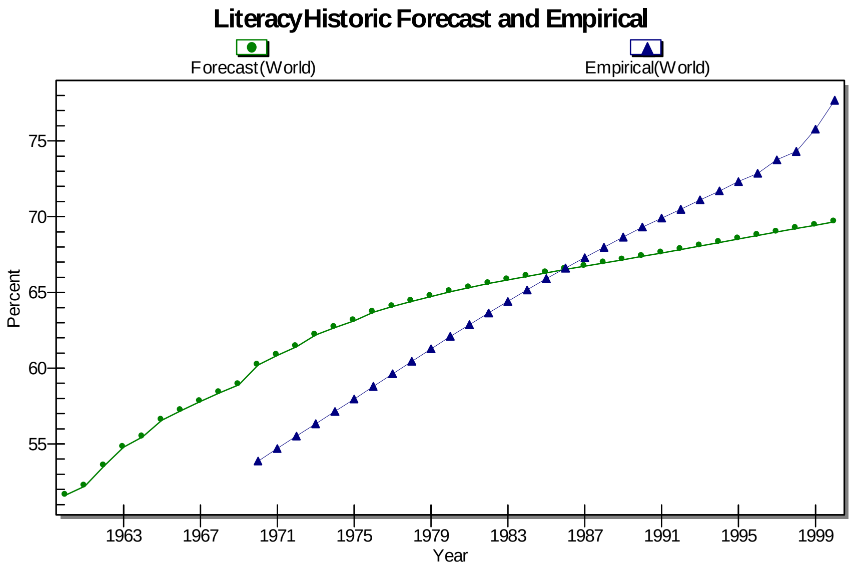
Educ Years Historic Forecast and Empirical

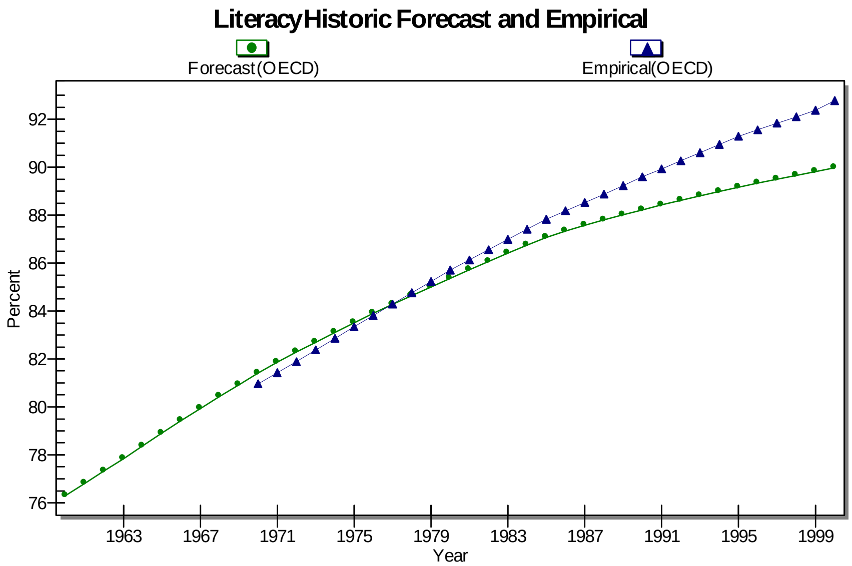


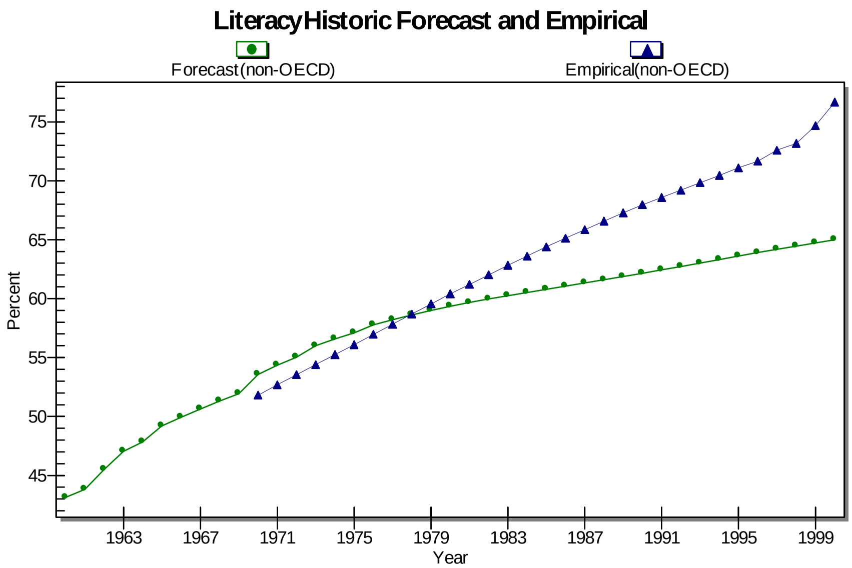
Educ Years Historic Forecast and Empirical

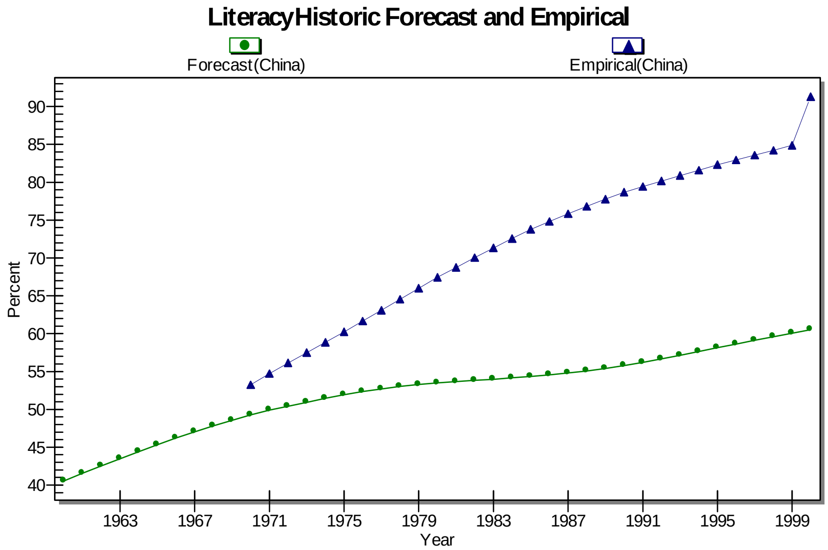


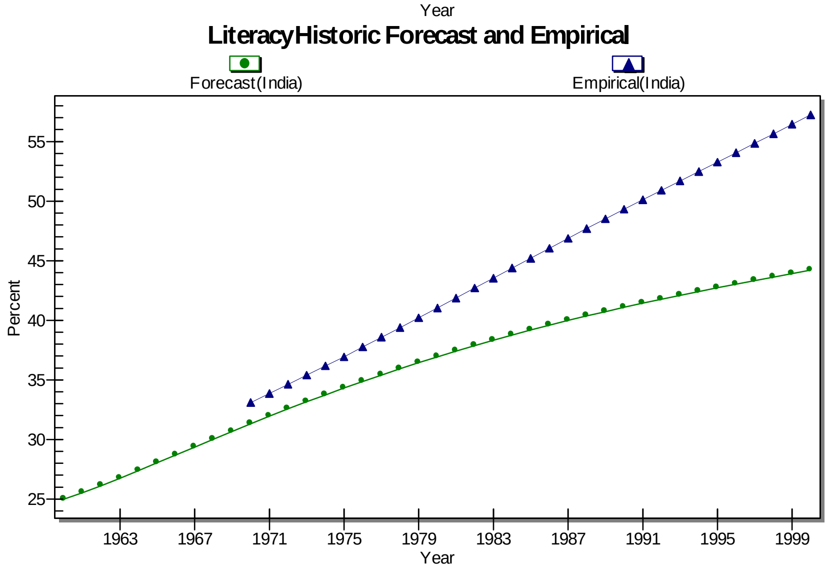
Years of education (and primary education in particular) relate directly to levels of literacy. The five graphs below show those levels for historic forecasts and empirically. Again, the scarcity of data for 1960 affects the fit of forecasts.



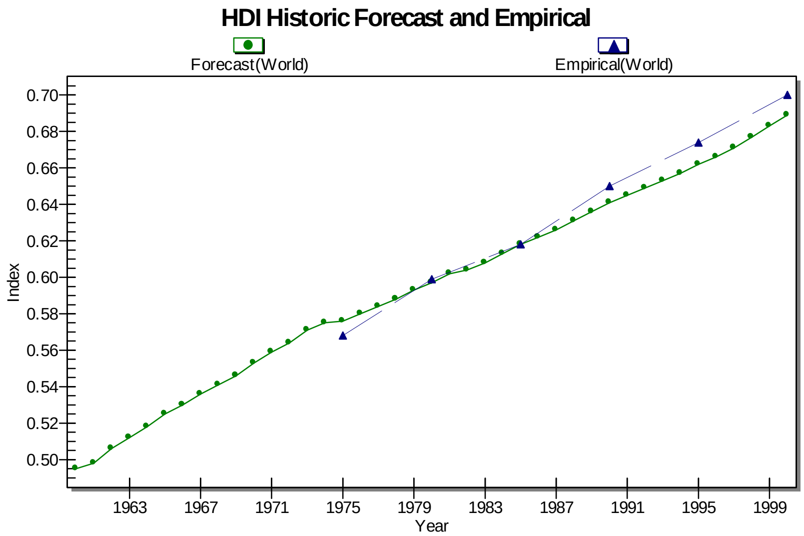


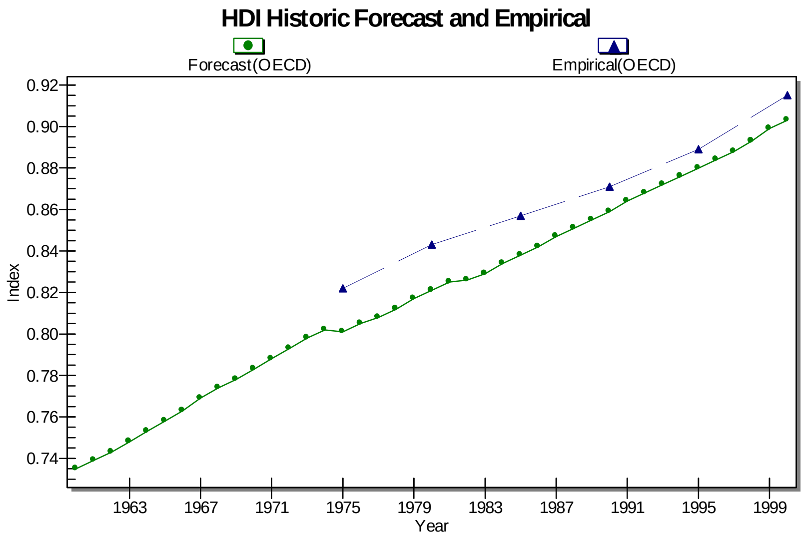

LiteracyHistoric Forecast and Empirical
Forecast(non-OECD)
Empirical(non-OECD)
Percent
Year

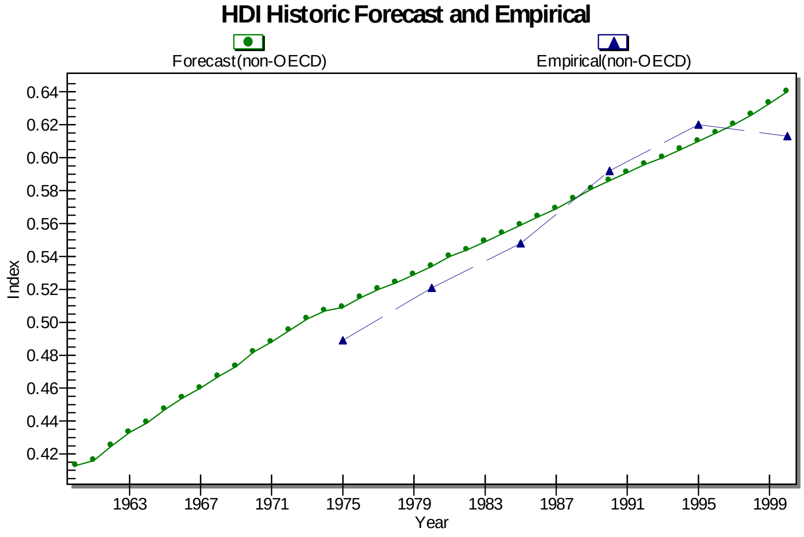

LiteracyHistoric Forecast and Empirical
Forecast(China)
Empirical(China)
Percent
Year

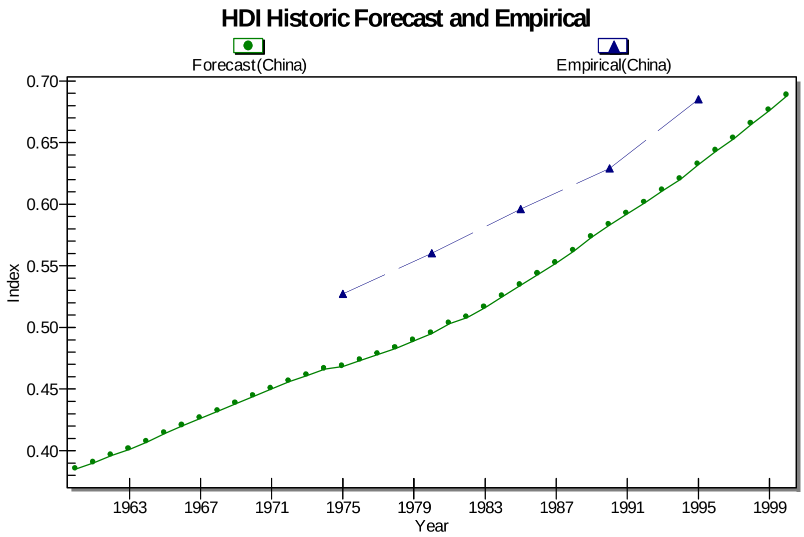

LiteracyHistoric Forecast and Empirical
Forecast(India)
Empirical(India)
Percent
Year

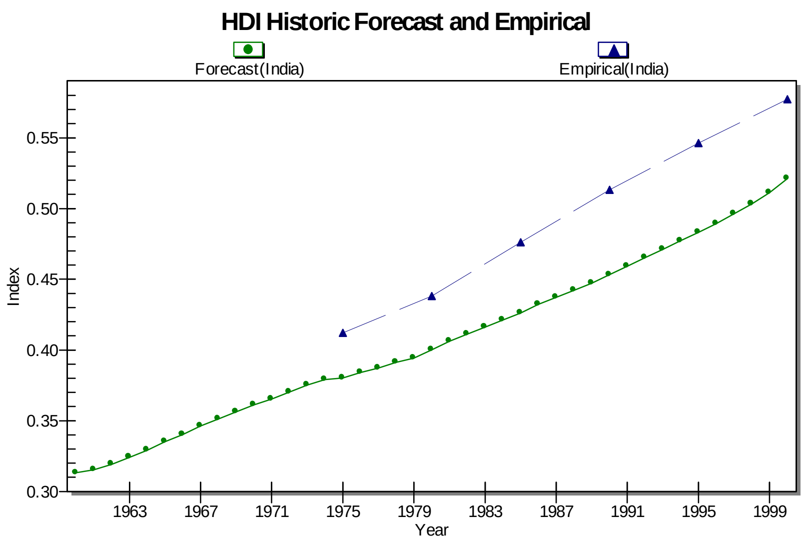
The human development index (HDI) builds on education, health, and basic economic conditions. It is a highly useful measure for assessing the overall human condition. Again, the five graphs allow comparison of historic forecasts with empirical values.



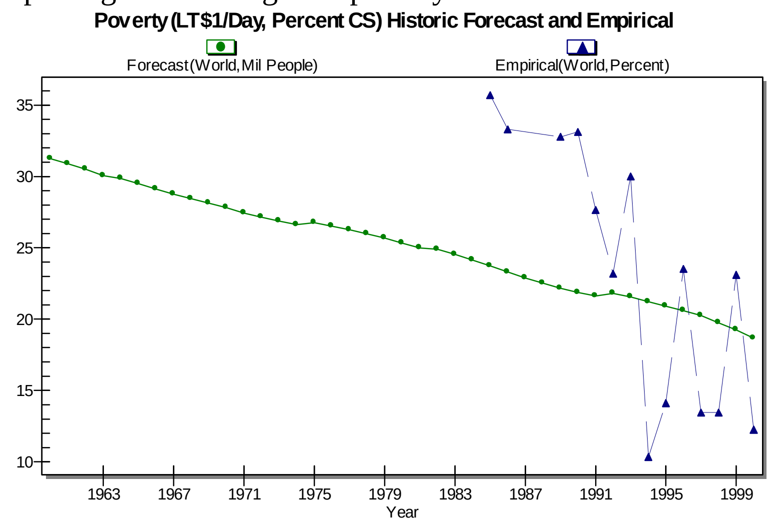


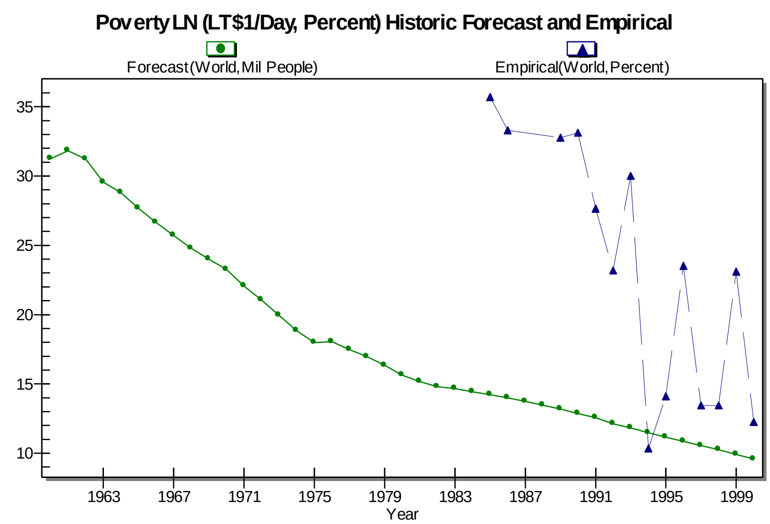

HDI Historic Forecast and Empirical
Forecast(non-OECD)
Empirical(non-OECD)
Index
Year
0.42
0.44
0.46
0.48
0.50
0.52
0.54
0.56
0.58
0.60
0.62
0.64
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999

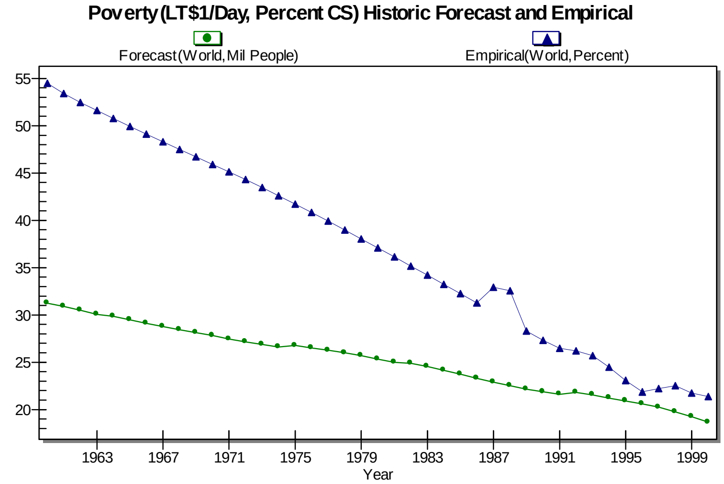

HDI Historic Forecast and Empirical
Forecast(China)
Empirical(China)
Index
Year
0.40
0.45
0.50
0.55
0.60
0.65
0.70
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999

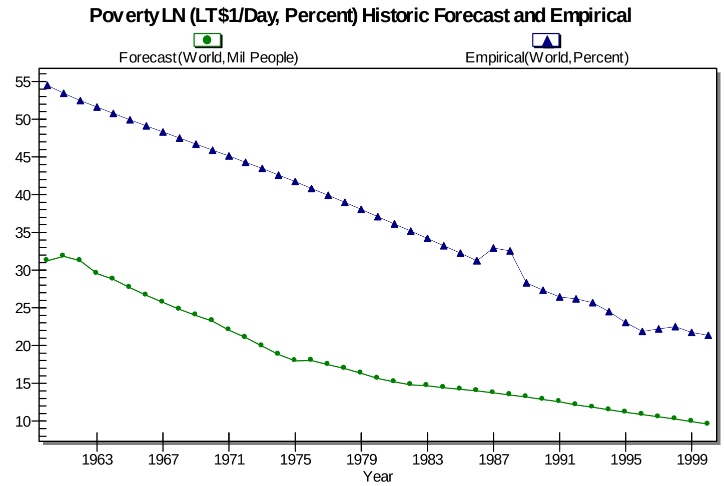

HDI Historic Forecast and Empirical
Forecast(India)
Empirical(India)
Index
Year
0.30
0.35
0.40
0.45
0.50
0.55
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999

Finally, we turn to absolute poverty, as measured by incomes of less than $1 per day. The graphs below are a preliminary representation of poverty in the historic base case, complicated greatly by the absence of significant data before 1985 and the highly incomplete character of data since that time. Two formulations for forecasting poverty are used, one based on cross-sectional analysis and one using a log-normal representation tied to household consumption per capita (see Hughes and Irfan December 2005). The first two figures show the results of historic forecasts for the two formulations against the very scarce empirical data, for the world only. The second two figures show the results of the same two formulations, plotted against an effort to smooth the data that do exist with interpolations and also to extrapolate the data back to 1960. The initial conditions for poverty rates in the historic forecasts are almost certainly too low, one of several issues that will need to be tackled as analysis around poverty continues in coming months and years. It also appears that the log-normal formulation may do a better job of capturing the rate of global poverty decline over the historic forecast period.









4.11 Analysis and Insight

What can one conclude from this historic calibration/validation exercise? One foundational conclusion is that forecasting over a 40 year-period, much less over 100 years as in the future horizon of IFs, is certainly going to produce some very mistaken forecasts. A large number of human interventions will influence a future with such a long horizon. A second and much more positive conclusion, however, is that the basic model, with the addition of known human actions, can fairly reasonable be generally calibrated to a period of that length – and such calibration can be done even though the problems with initial conditions are often much greater in 1960 than in 2000. This fact adds some basic credibility to both the model and the nature of its response to interventions.

What kinds of interventions are most important to consider both historically and prospectively? They include:

- Major global transformations such as the end of the Cold War, the wave of democratic retrenchment in the 1960s and 1970s, and the wave of expansion of economic liberalization with associated globalization in the 1980s and 1990s. Another example is the one-off transfer of medical technology and therefore of increased life expectancy to developing countries after 1960.

- Global technological waves such as the drop in economic productivity growth rate in the 1970s.

- Large-scale shocks to the global system, such as the energy shocks of the 1970s and early 1980s.

- Substantial country-specific policy-based swings such as the one-child policy of China and, even more significantly, its economic liberalization of the 1980s and 1990s. Such swings are most pronounced in one-time command economies, including those of Central and Eastern Europe, suggesting that this might be a somewhat less disruptive force in forecasts beyond 2100.

For the most part, the intervention types listed above reflect policy choices, and even shifts in policy direction. A model like IFs must use scenario analysis to represent such choices and shifts, an issue to which Chapter 7 will return.

5. Testing and Analysis: Forecasting

There is no question that understanding the conceptual and theoretical foundations of the model (Chapter 3) are essential to having any confidence in its forecasts. And there is no doubt that seeing the ability of the model generally to match a historical period (Chapter 4), using relatively few interventions, provides some additional confidence (although the reader should remember that the last chapter looked at relatively few countries and regional groupings; there will be some very large discrepancies in historic forecasts and data for many countries and many issues).

Yet these two steps in the gradual process of a model's "accruing of validity" are definitively inadequate. Two additional steps are necessary. The first, to be taken in this chapter, is the reviewing of the base case forecast of the model as both a continuation and alteration of historical patterns. The second, to be taken in the next chapter, is a wider and more focused examination of the future behavior of the model in the face of interventions (as opposed to, but building on the examination of interventions in the historic analysis).

With respect to the examination of the base case in this chapter, there are three focal questions of particular attention:

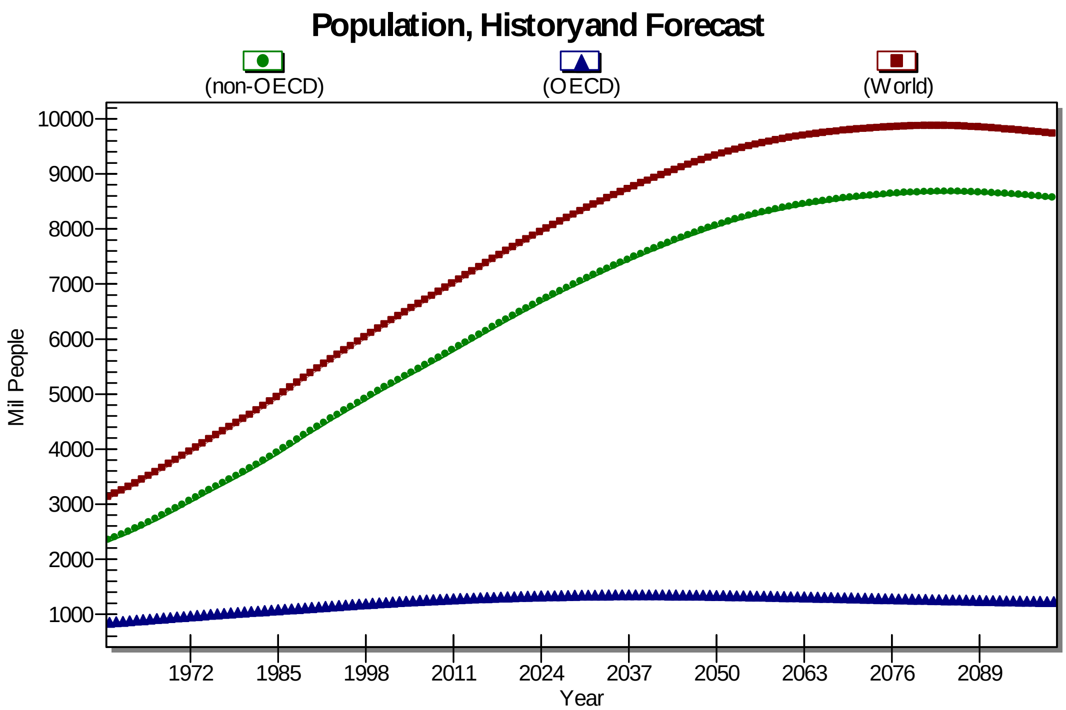
1. Does the model, for the most part, smoothly extend historical patterns, without major transients or strange and unexplained twists or bends?
2. Does the model exhibit reasonable behavior as variables begin to approach obvious limits or turning points? These might include oil production in the face of limitations in reserves and broader resources; life expectancy in the face of possible ultimate limits on it – or not if those limits are assumed away; calorie consumption per capita in the face of upper limits on human needs.
3. Does the model behave comparably with other forecasts, especially highly credible and respected ones, unless there is some sound explanation for why it differs and may be preferable?

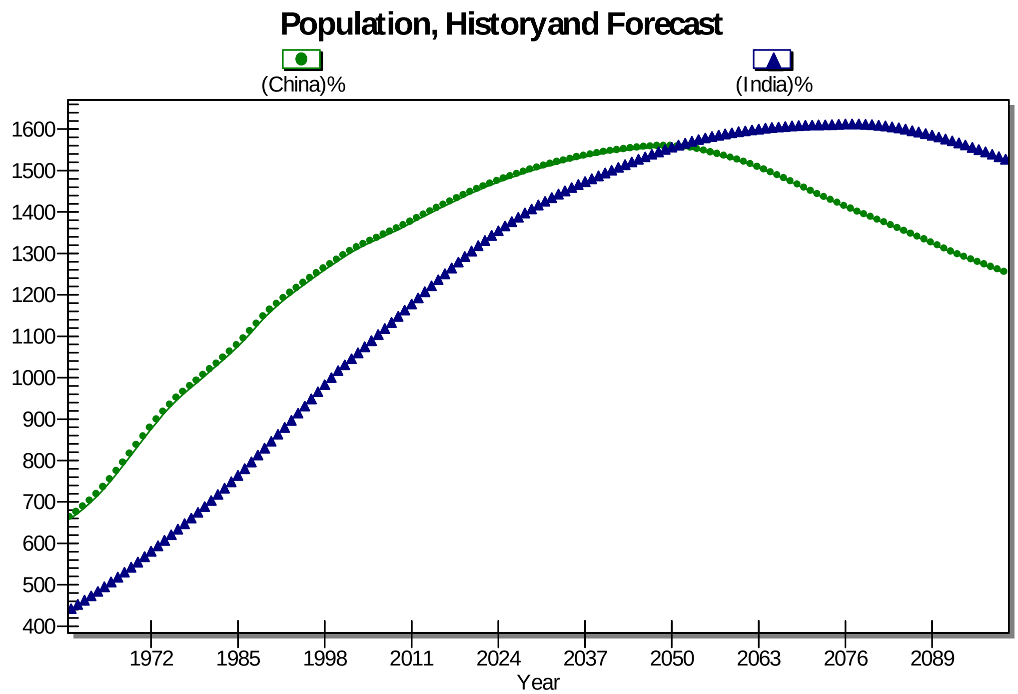
Hughes (March 2004), "The Base Case of International Futures (IFs): Comparison with Other Forecasts" explored these three questions, especially the third, at greater length than is possible here. This chapter will more narrowly walk once again through the major substantive areas of the model and show the general behaviour of it in the base case over its full 100-year horizon and as an extension insofar as possible of historical data. That is, the attention will be on the first two questions.[4]

[4] The base case of IFs constantly changes with new data and assumptions. The analysis here was built from version 5.26.

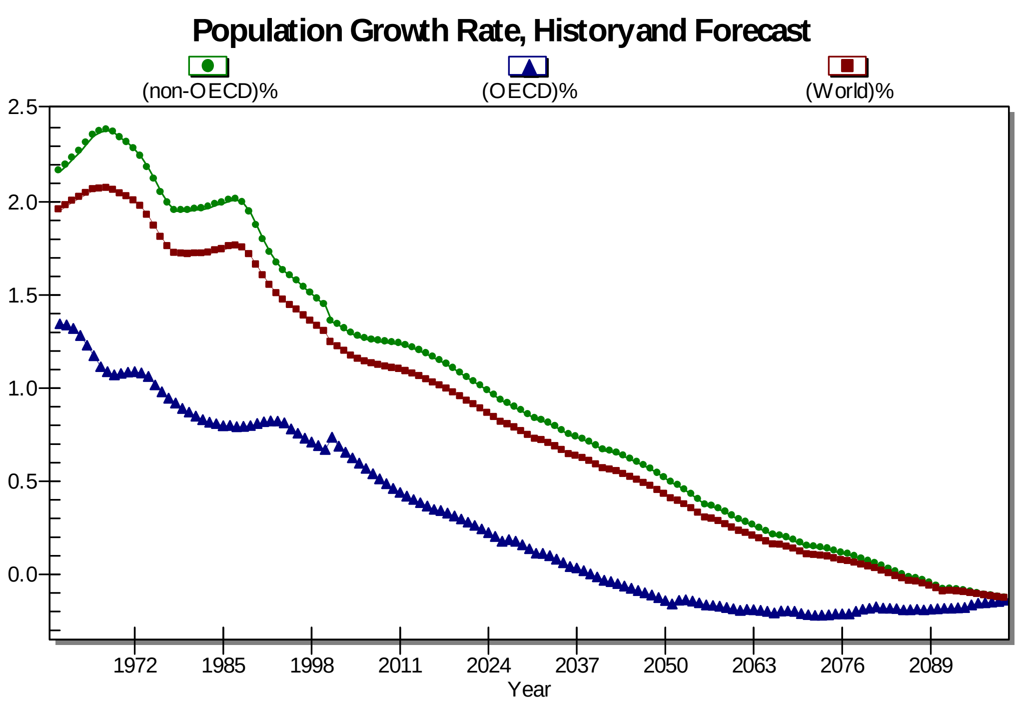
5.1 Population

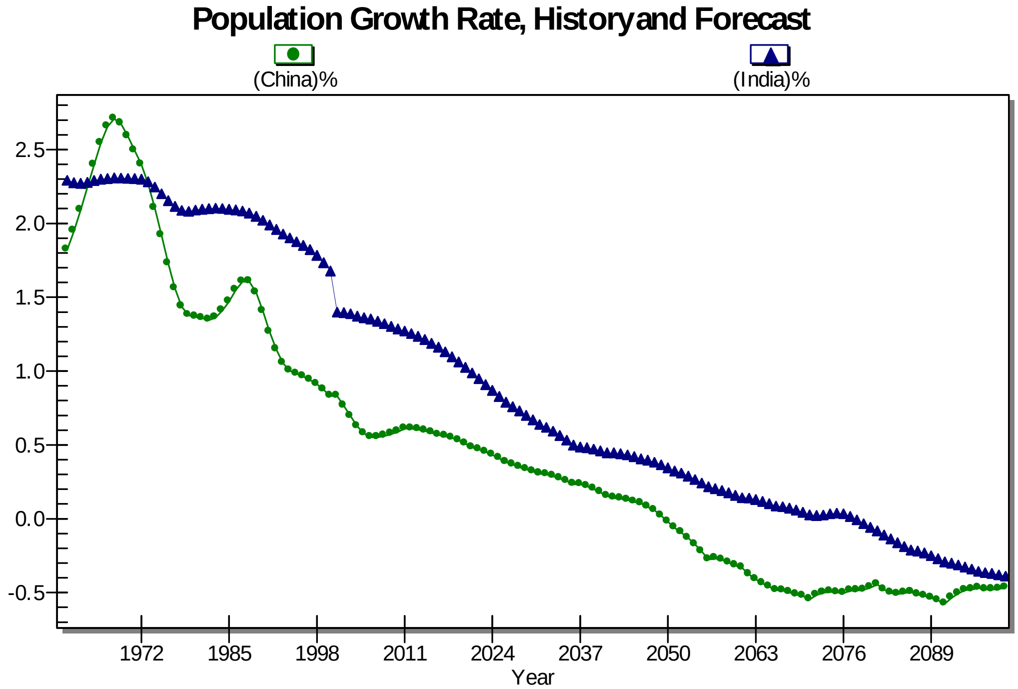
The two figures below show the base case forecast of population. The first looks at the world as a whole, OECD countries, and non-OECD countries. The base forecast is clearly a smooth continuation of the last 40 years, but also moving towards and past a peak of global population. As Hughes (December 2004) discusses, this pattern is very comparable to forecasts produced by the United Nations, the U.S. Census Bureau, and the International Institute for Applied Systems Analysis (IIASA). The second graph in this set looks at the demographic giants, China and India.



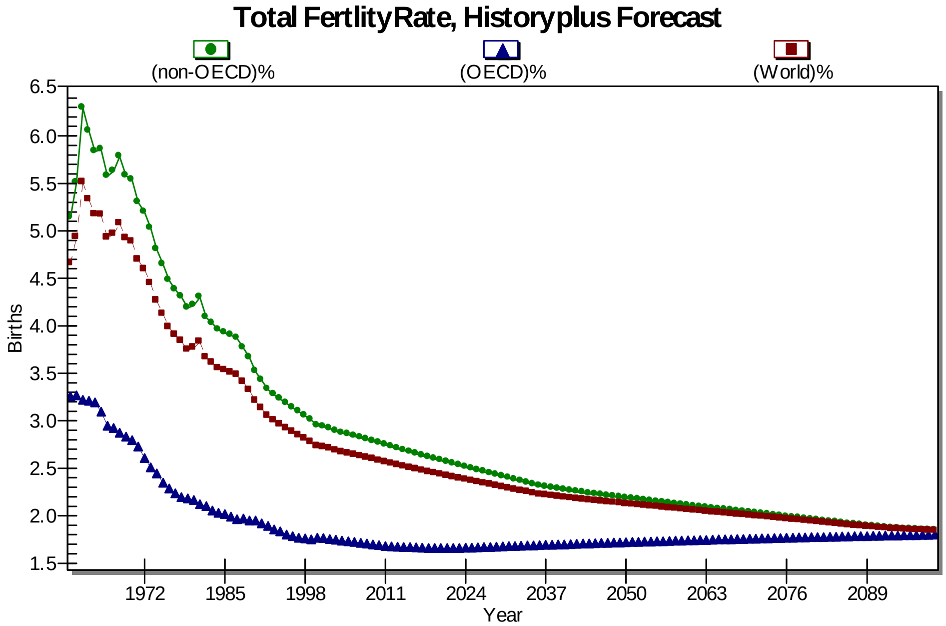


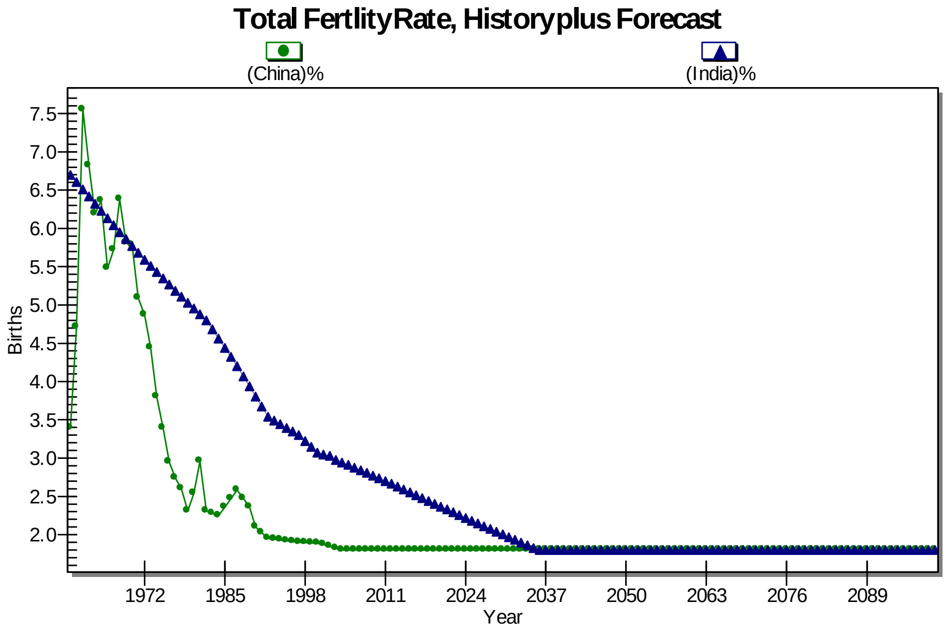
Moving from population to population growth rates, the next two figures cover the same geographic entities as the last two. The pattern of change in rates, while clearly a continuation of past years, is smoother in the forecast than in the empirical data of the 1960-2000 period for an obvious reason: the forecasts do not contain shocks like those of that past. In particular, the historic pattern in China, which can demographically affect the world, has been irregular as a result of the Great Leap Forward (with a bounce-back of fertility from it in the early 1960s) and other policy changes historically.



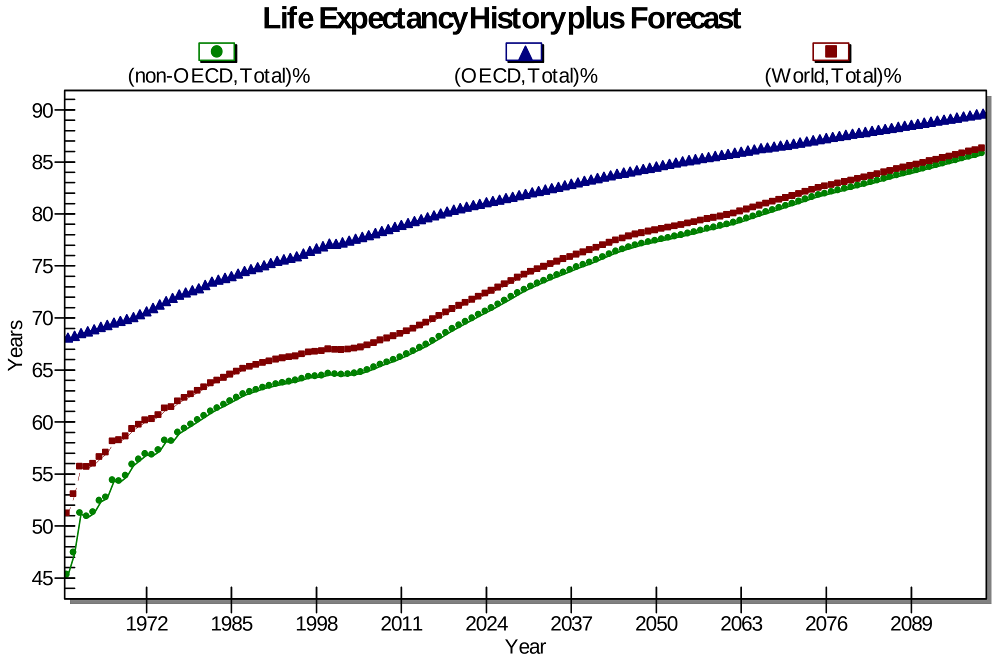


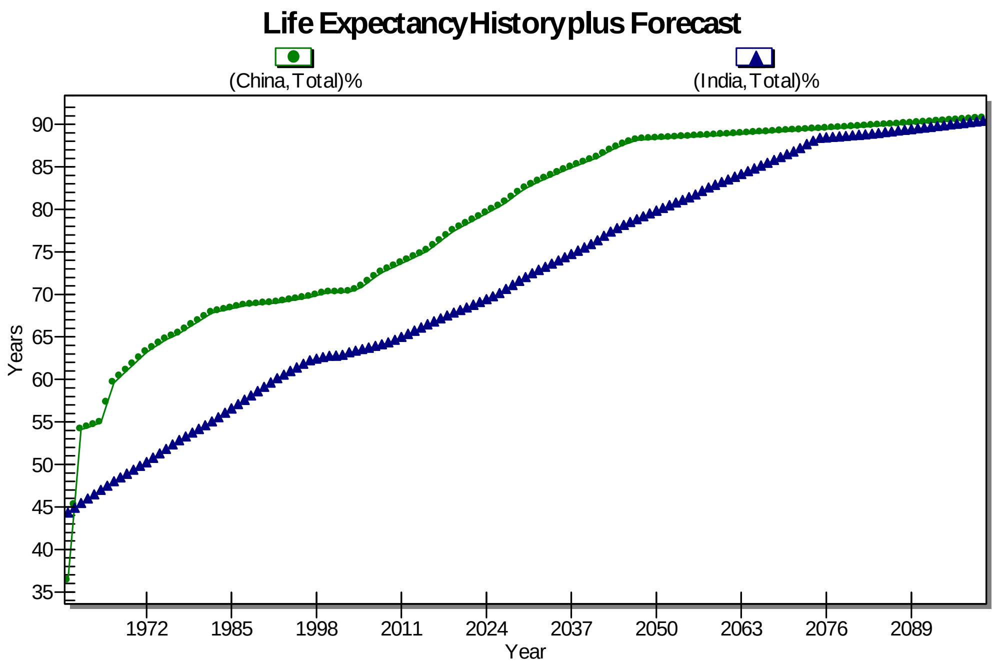
Moving to fertility rates, the two graphs below reinforce some of the patterns and information of the two above.





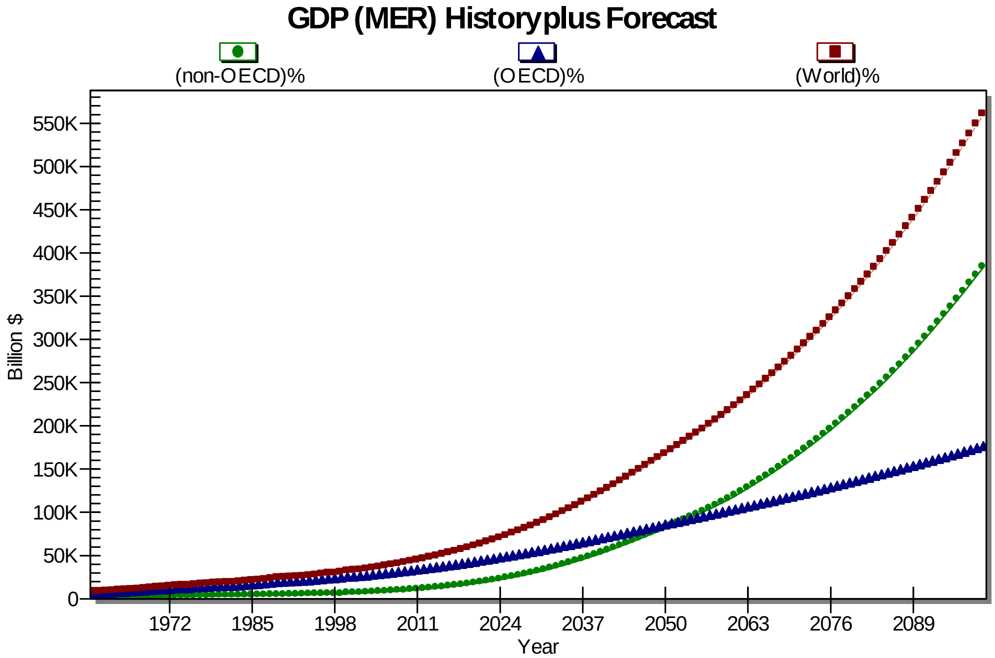
The following graphs turn to life expectancy. There is a substantial debate in the long-term forecasting community between those who see a biological limit on life expectancy that is unlikely to let it push beyond about 85-90 years for an aggregate population (influenced by the Hayflick limit on cell divisions) and those who believe it can and will be expanded much further. The historic pattern of OECD countries clearly suggests a saturating curve and a continuation of that pattern is built into the base case of IFs (although scenarios like those in the next chapter would allow alternative patterns).

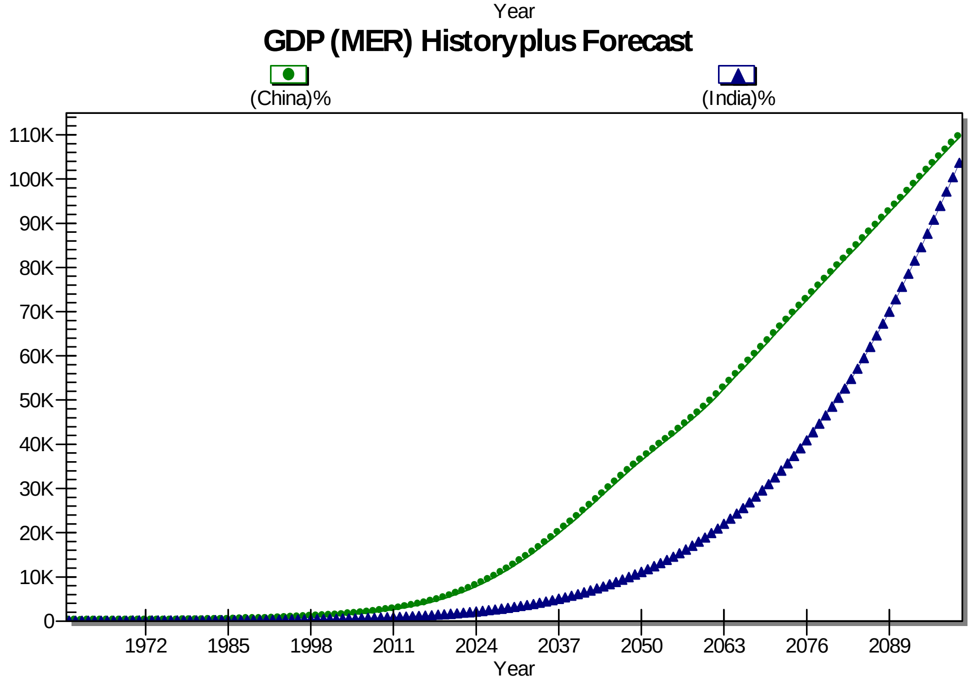




5.2 Economy

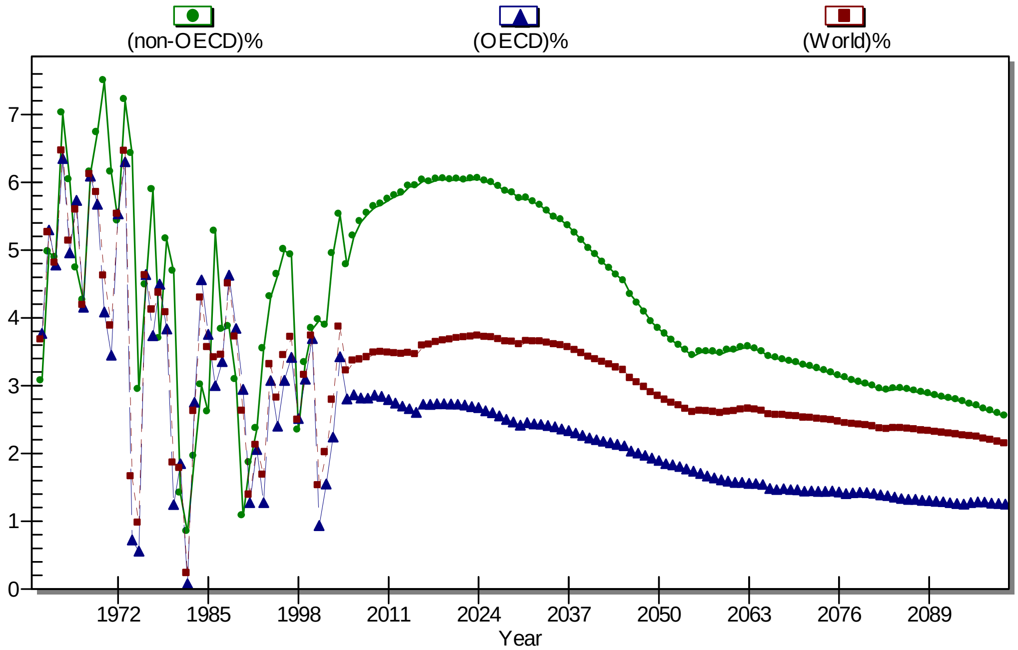
The two graphs below show the historical data and long-term IFs forecast for GDP at market exchange rates (MER) for the world, OECD countries, non-OECD countries, China and India. They clearly show the shift of global economic power over time to the global South, as well as the remarkable long-term rise of the two prospective new global superpowers.



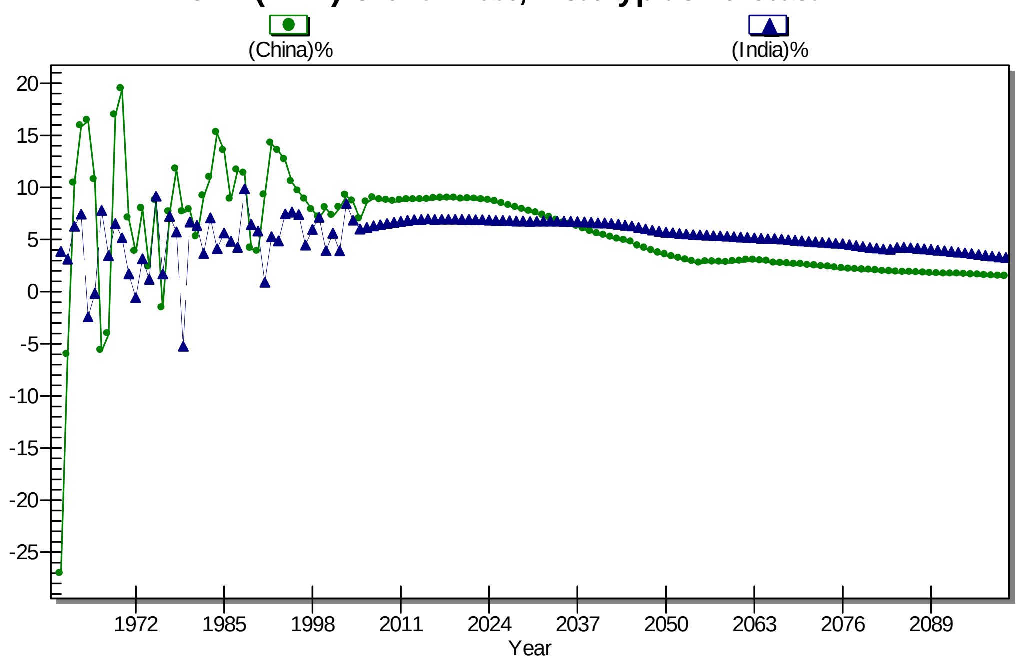


The figures below move to GDP growth rates. The values in the base case forecast for non-OECD countries through much of the first half of the century are historically high, heavily influenced by the recent experiences of China and India.

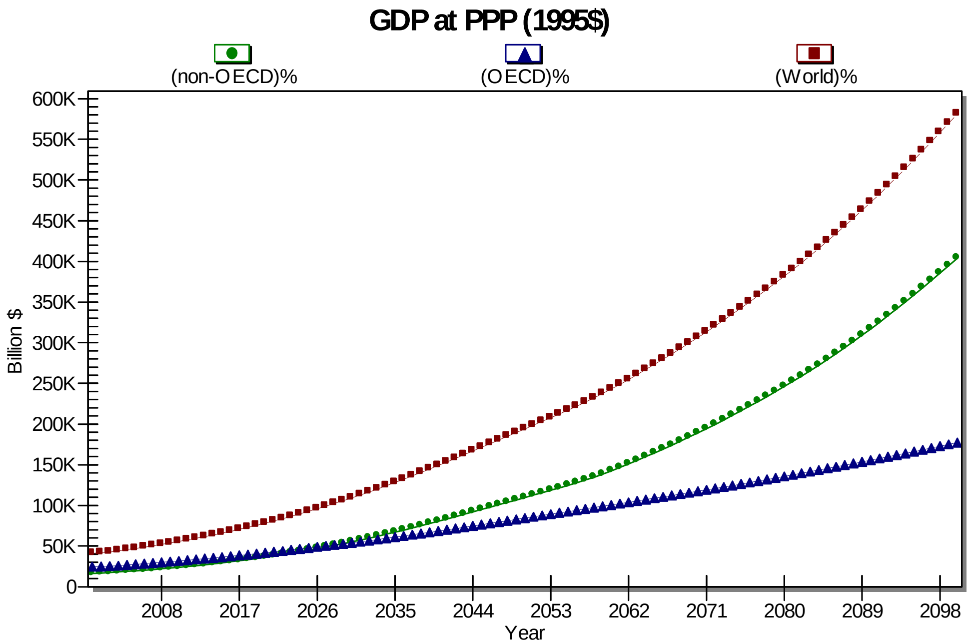
GDP (MER) Growth Rate Historyplus Forecast

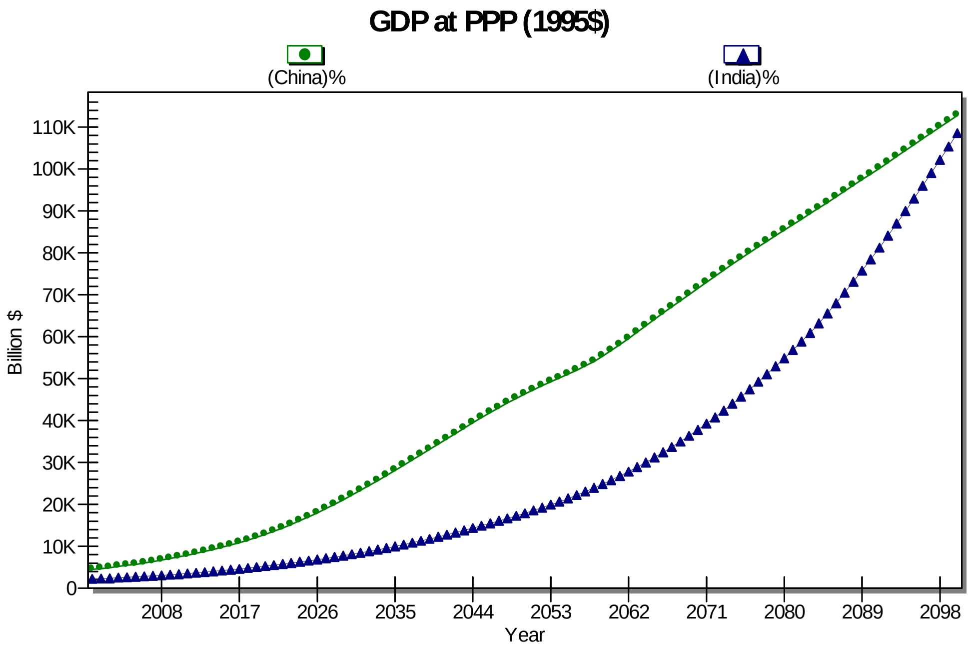


GDP (MER) Growth Rate, Historyplus Forecast



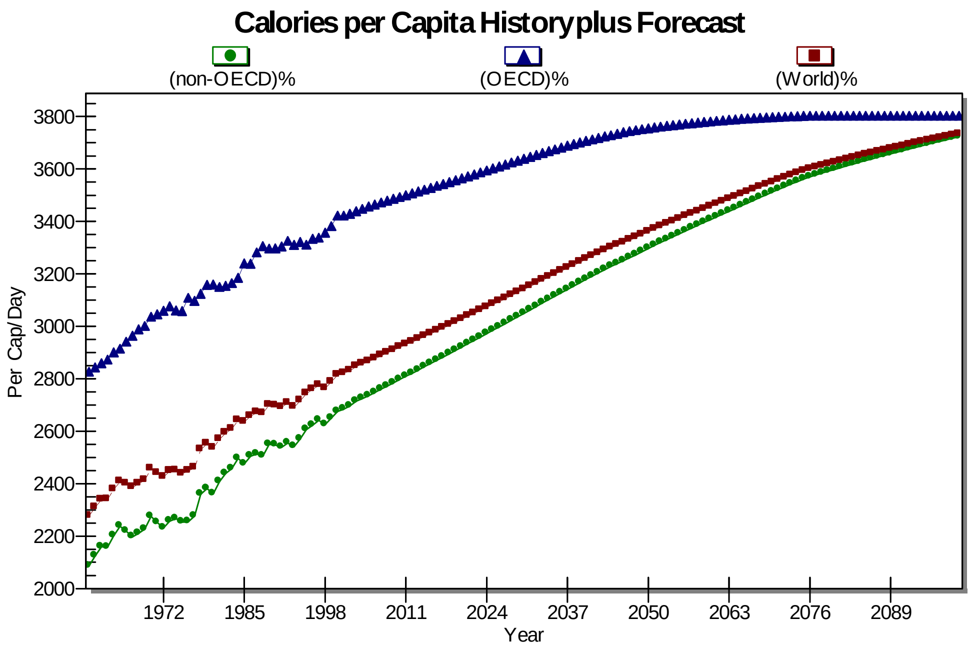
The two figures below turn to GDP per capita at purchasing power parity. They raise one of the contentious issues of very long-term economic forecasting. A forecast of GDP per capita reaching nearly $160,000 in OECD countries by the end of the century will strike some observers as a logical extension of long-term growth patterns that brought it to about $23,000 (at PPP) in 2000. It will strike other observers as an environmentally impossible (or at least as a very highly undesirable) forecast and perhaps one that raises also issues of human values. Similar debates would certainly swirl around the high levels forecast for China and India in 2100. In this instance, the IFs base case has not included forces that would "bend the curve." Many scenario analysts would want to do so.

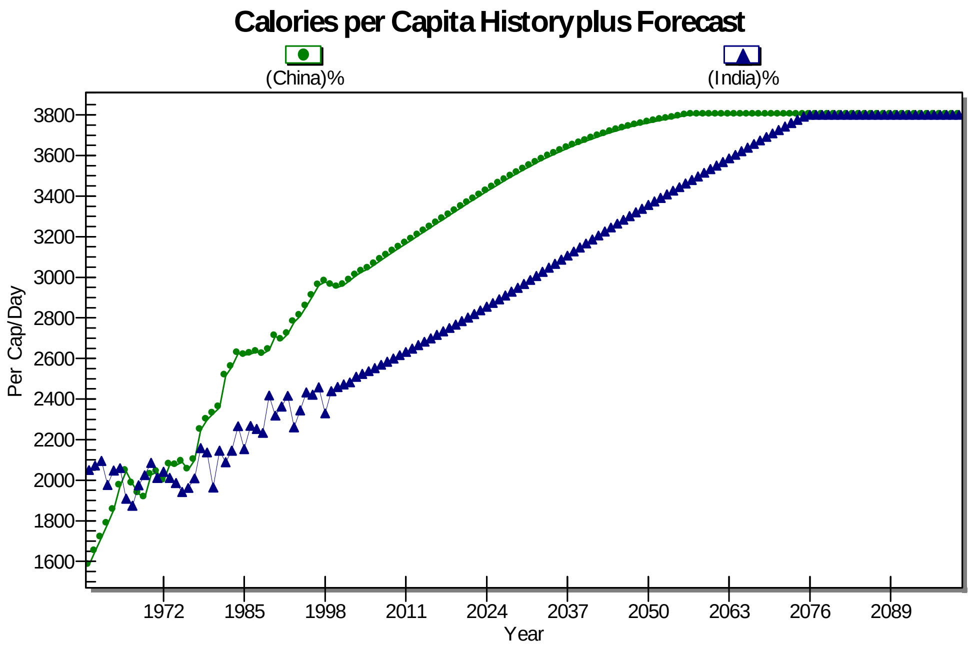




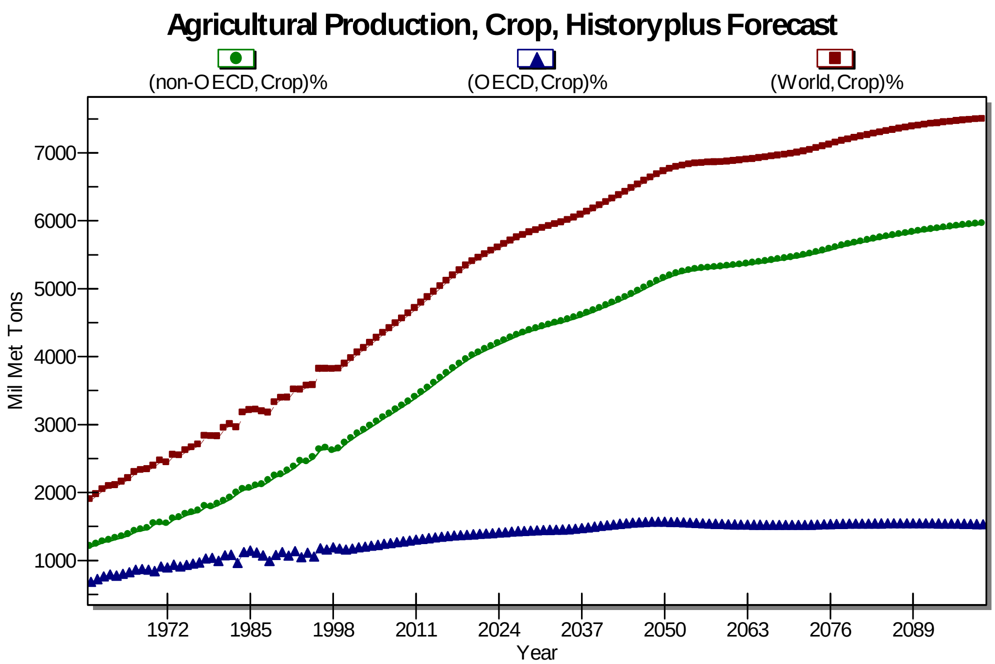
5.3 Food and Agriculture

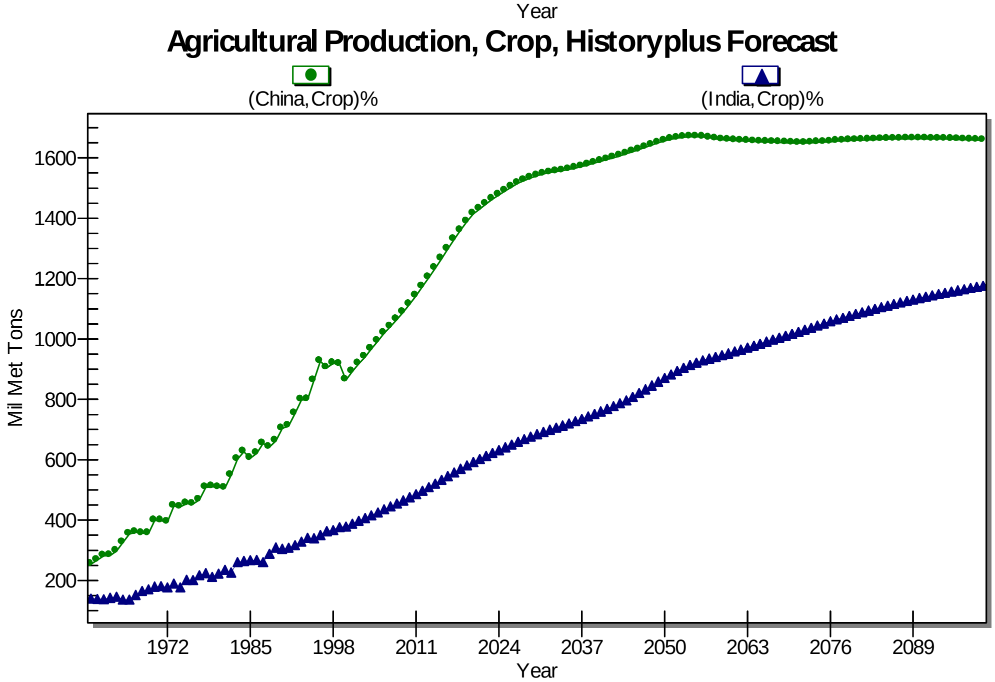
In contrast to the forecast of economic growth, above, that did not include automatically saturating patterns, those for calories per capita do so. There can be little debate about the inevitability of such consumption saturating, probably near or below levels that the richest countries of today have already reached. The United States is just barely below 3800 calories per day on average and the obesity epidemic suggests that future levels should actually be lower. For some countries, India included for cultural reasons with respect to diet, the saturation level could well prove to be substantially lower.

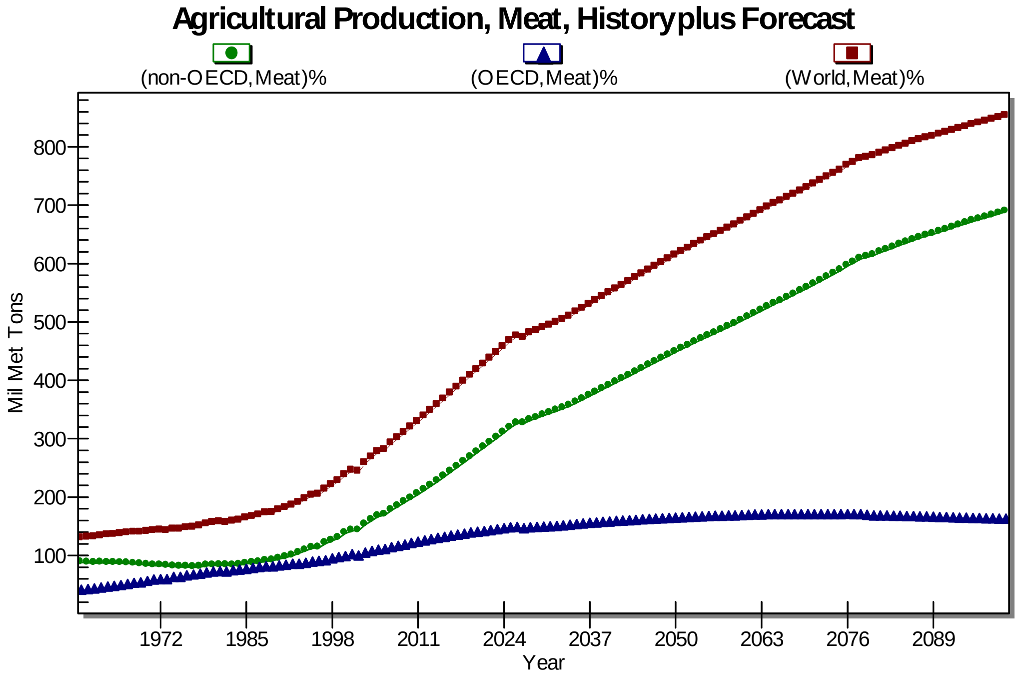


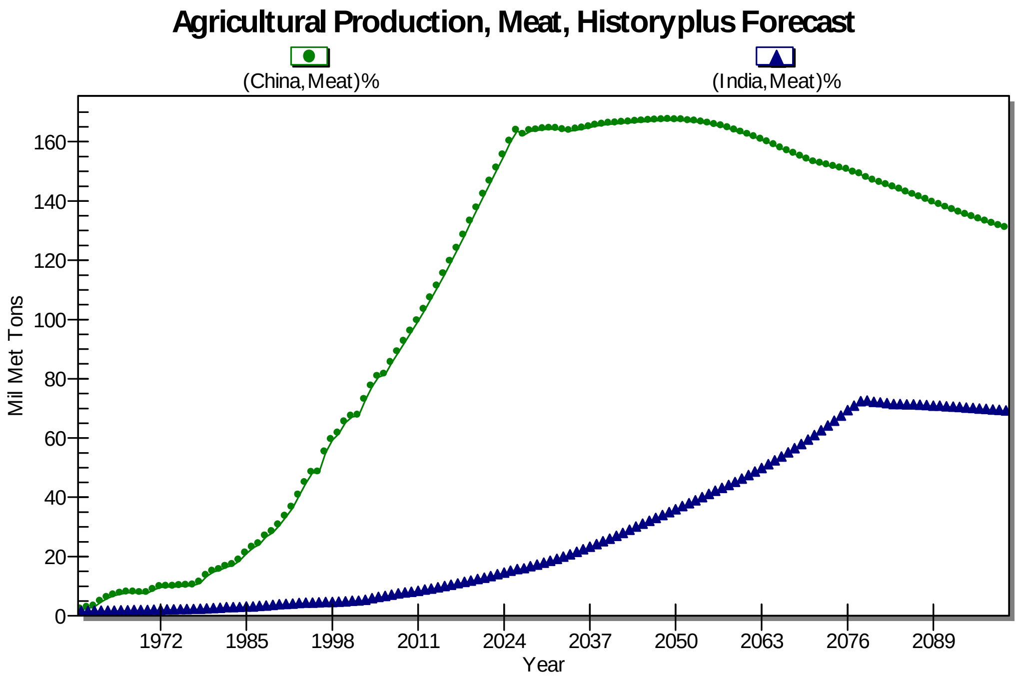


The two figures immediately below show crop production, and the following two show meat production. The saturation of production, related primarily to peaking of global population and to saturation of calorie needs, but also to the specifics of production patterns in different countries and regions dominate the long-term patterns. In developing countries as a whole, another doubling of crop production is anticipated, with even somewhat greater rise in meat production. Again, there could easily be debates about the possibility and desirability of the pattern.

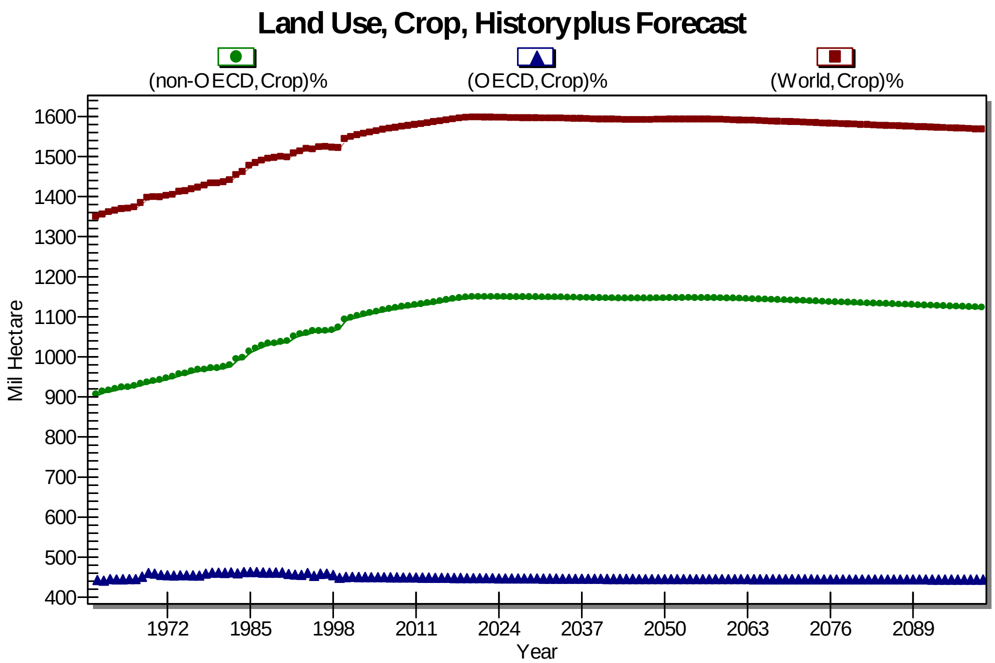




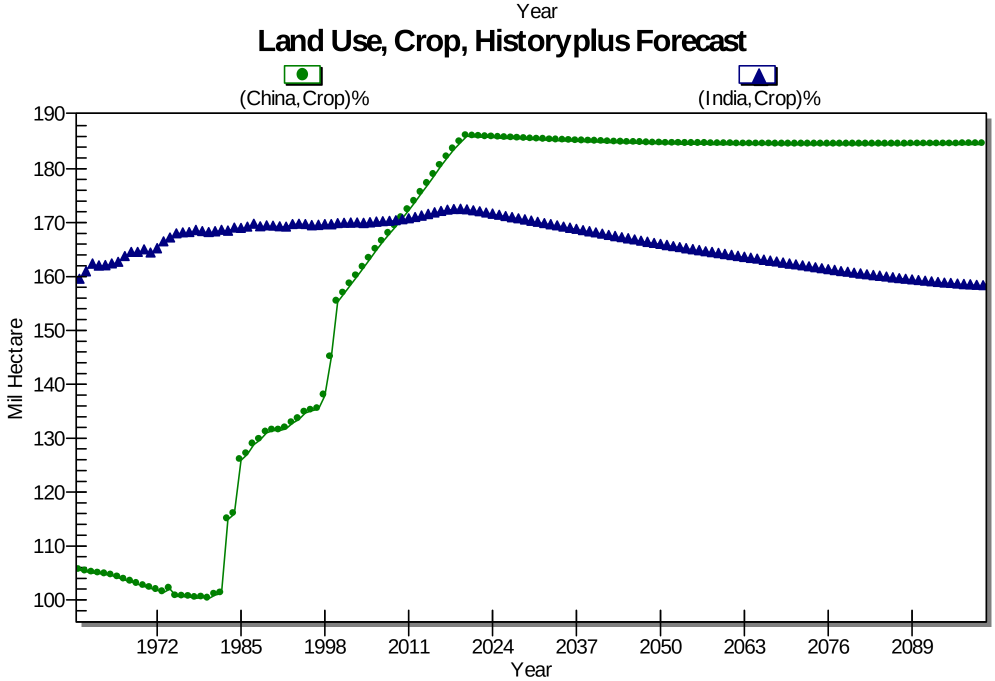




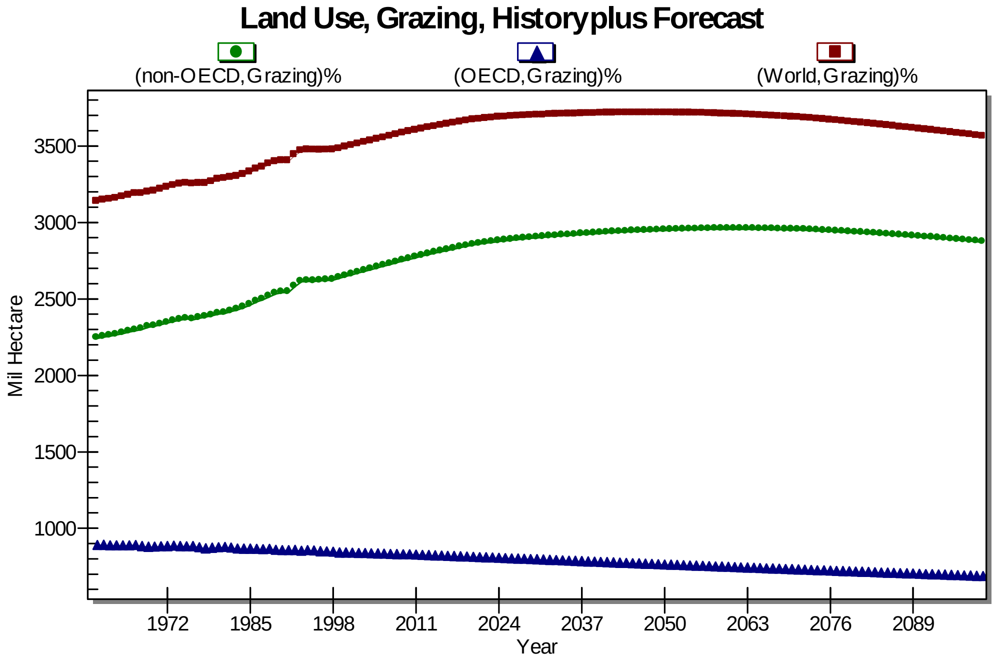
The six figures below move attention to land use, two each for land devoted to crops, grazing, and forest. Perhaps the most striking features of them are the relatively small amount of change within each category. The ending of net deforestation and a low level of net reforestation also appears.

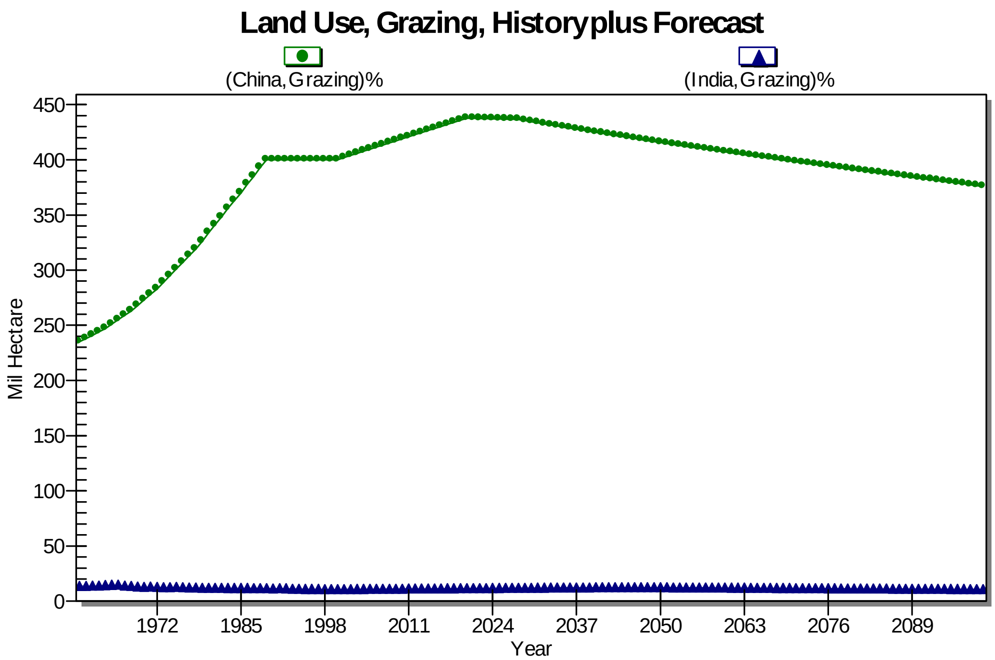


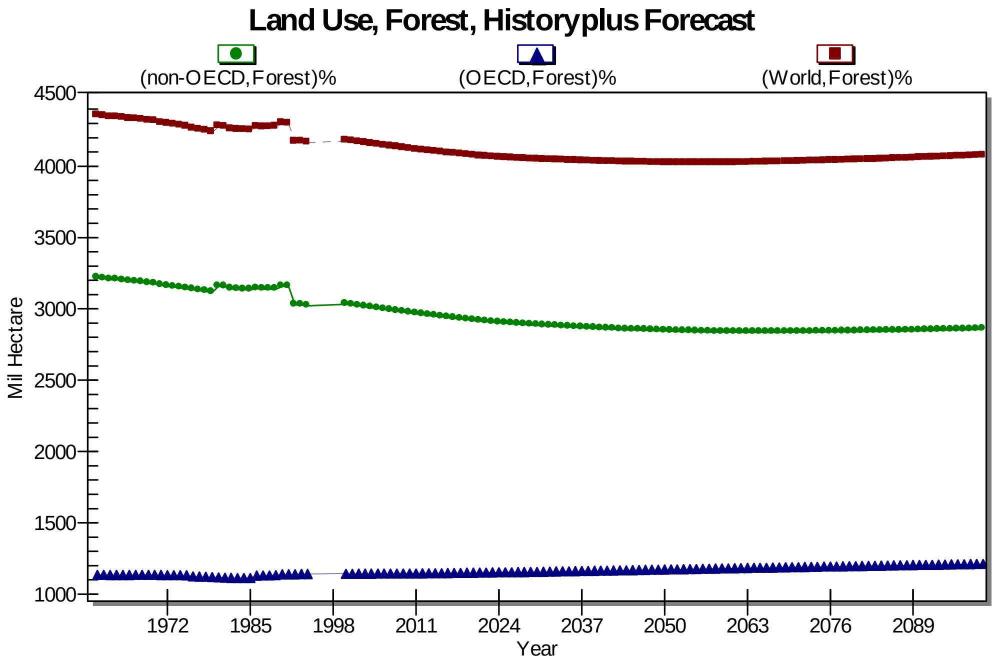
Land Use, Crop, Historyplus Forecast
(non-OECD,Crop)%
(OECD,Crop)%
(World,Crop)%
Mil Hectare
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
1972
1985
1998
2011
2024
2037
2050
2063
2076
2089
Year

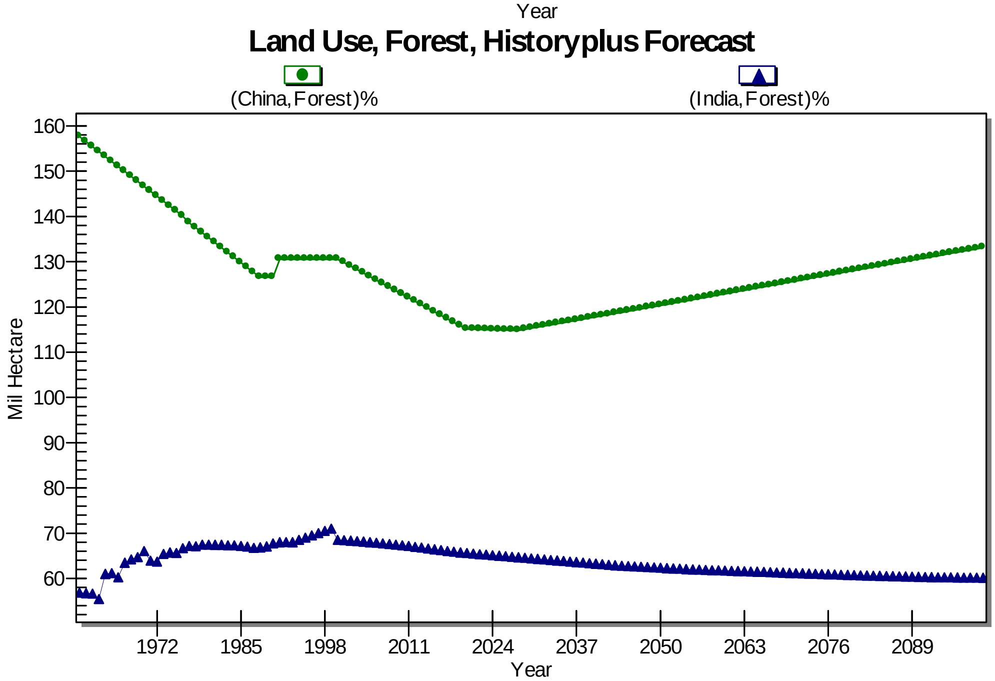


Land Use, Crop, Historyplus Forecast
(China,Crop)%
(India,Crop)%
Mil Hectare
190
180
170
160
150
140
130
120
110
100
1972
1985
1998
2011
2024
2037
2050
2063
2076
2089
Year


Land Use, Grazing, Historyplus Forecast
(non-OECD,Grazing)%
(OECD,Grazing)%
(World,Grazing)%
Mil Hectare
3500
3000
2500
2000
1500
1000
1972
1985
1998
2011
2024
2037
2050
2063
2076
2089
Year

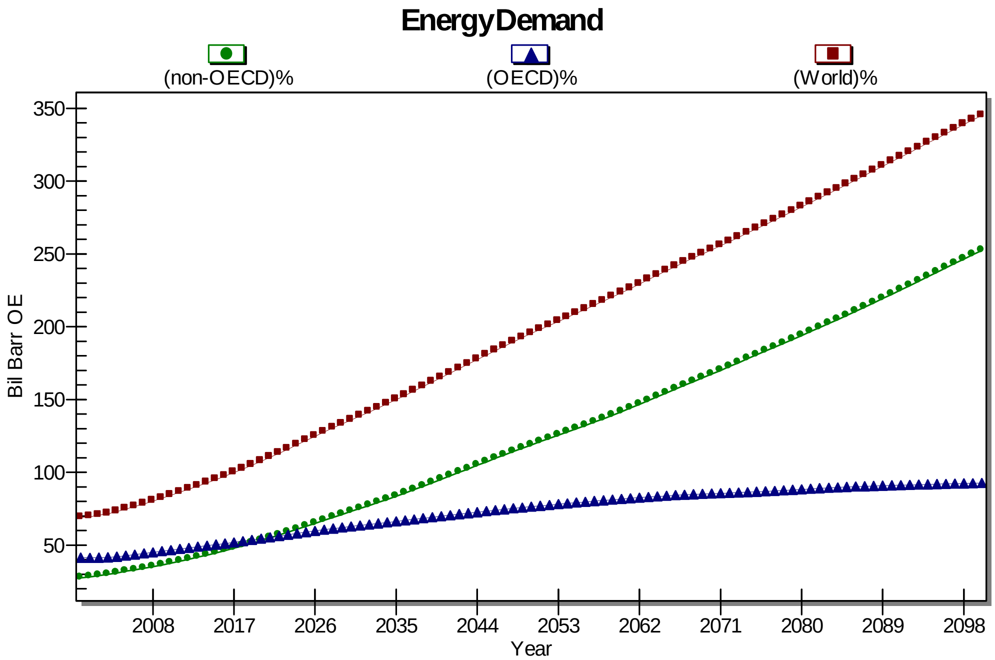

Land Use, Grazing, Historyplus Forecast
(China,Grazing)%
(India,Grazing)%
Mil Hectare
450
400
350
300
250
200
150
100
50
0
1972
1985
1998
2011
2024
2037
2050
2063
2076
2089
Year

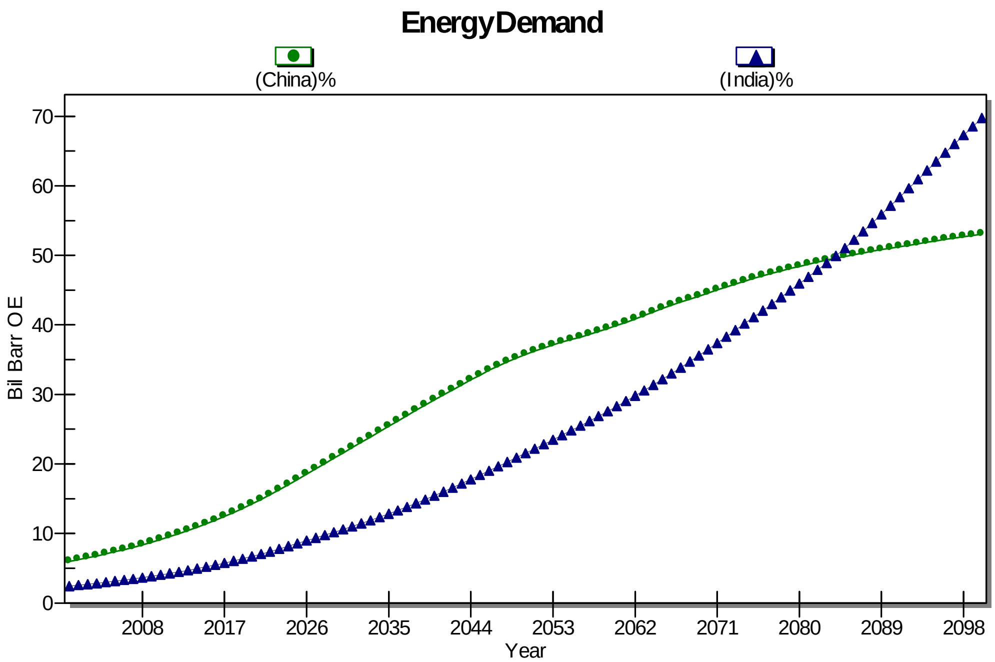




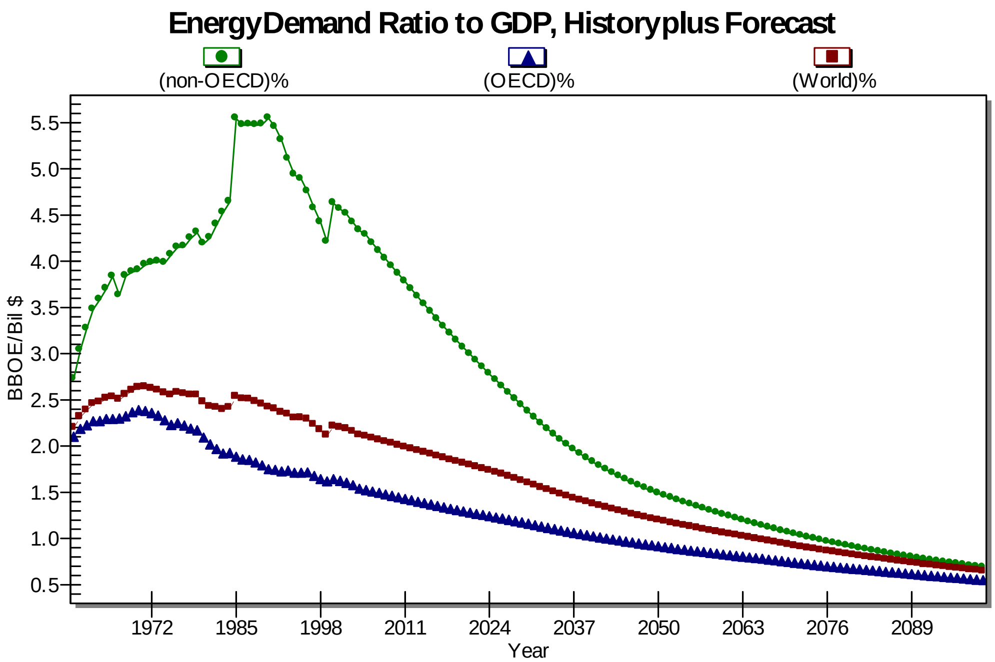
5.4 Energy

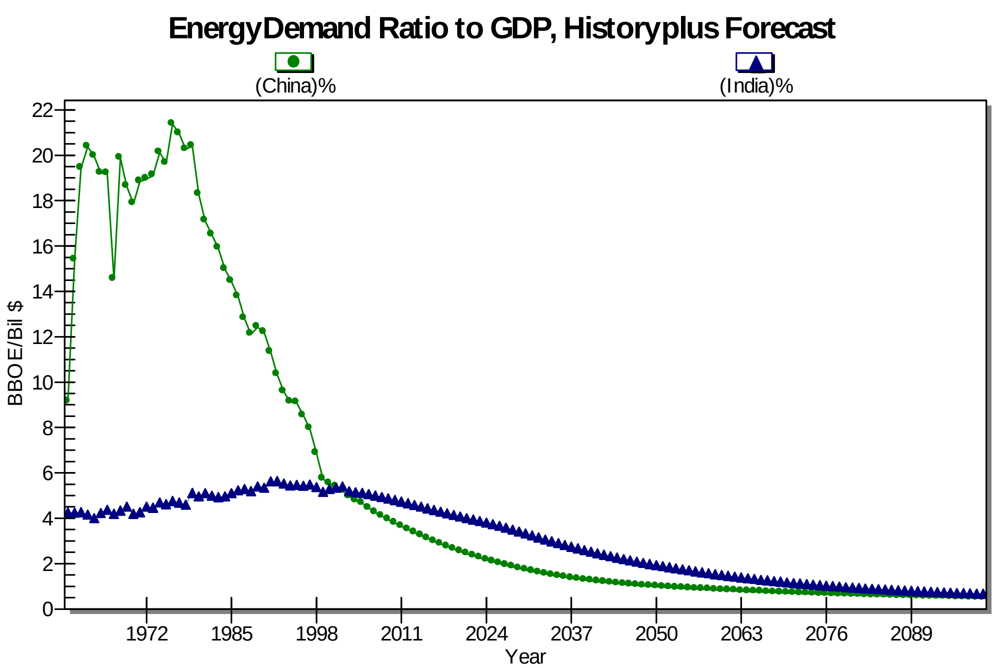
The two graphs below begin the discussion of energy with energy demand, the ultimate interest of humans.



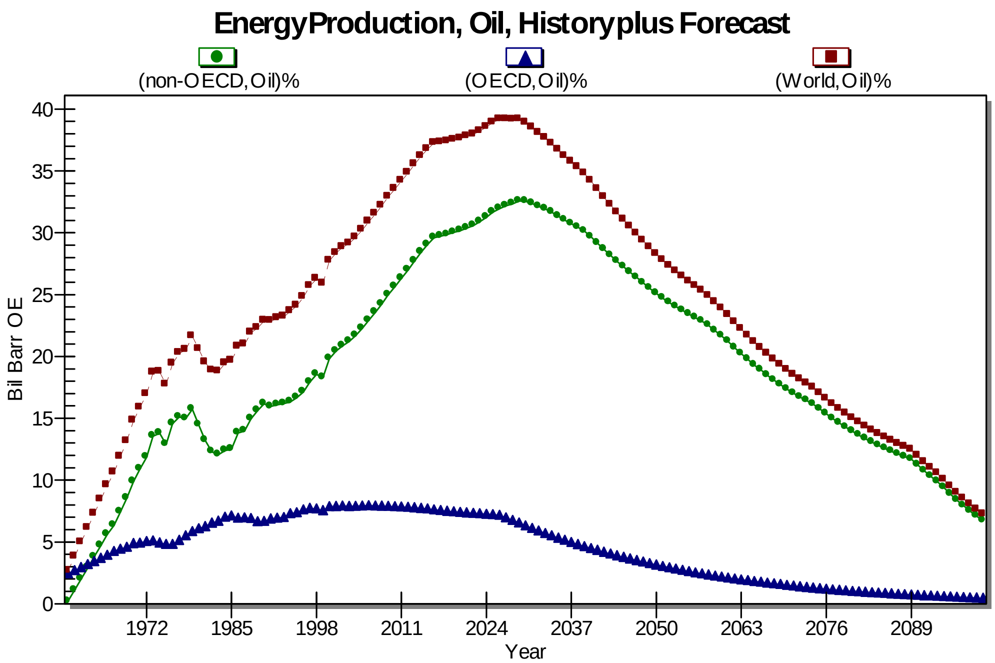


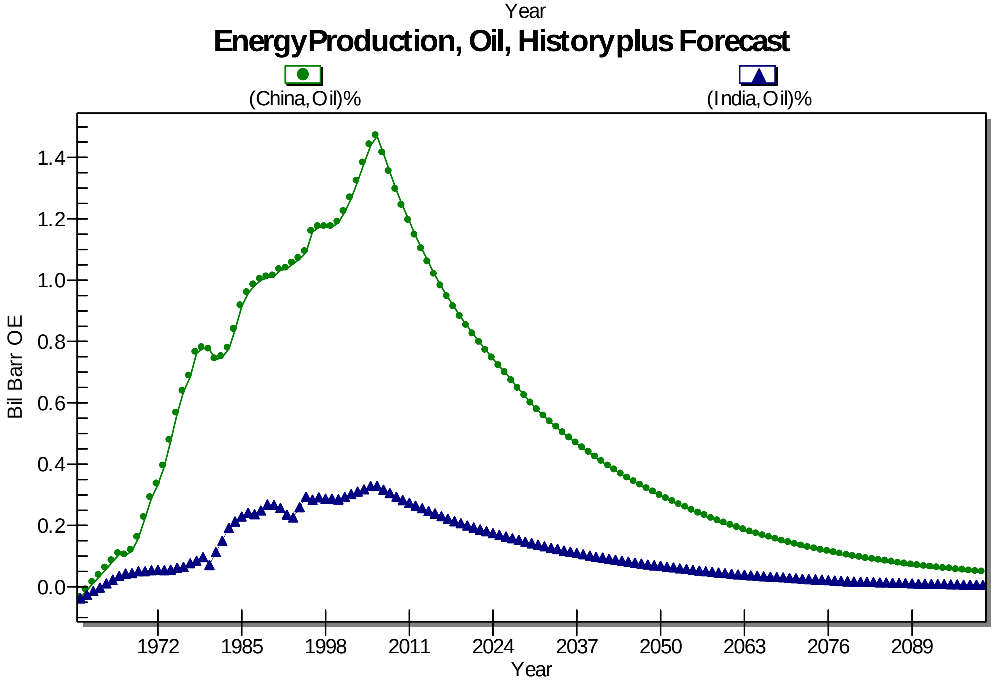
Energy demand is a function of GDP and the ratio of demand to GDP, so the two graphs below turn to the critical relationship of energy demand to GDP. Note the historic reversal of the growth in the ratio for non-OECD countries, sometimes referred to as the energy Kuznet's curve. In these figures, and especially for China, it has more to do with the movement from centrally-planned, energy-inefficient economies to market economies in which the real price of energy affects consumption behavior. One of the key forecasting questions is how to extend the pattern of extremely rapid historic decline in that ratio for China; the IFs base case bends the curve immediately in the forecast, because rapid continuation for any length of time looks highly improbable (see the pattern of India for comparison). Note: the transient in the year 2000 for non-OECD countries below reflects the lack of historic energy demand data for a number of those countries.

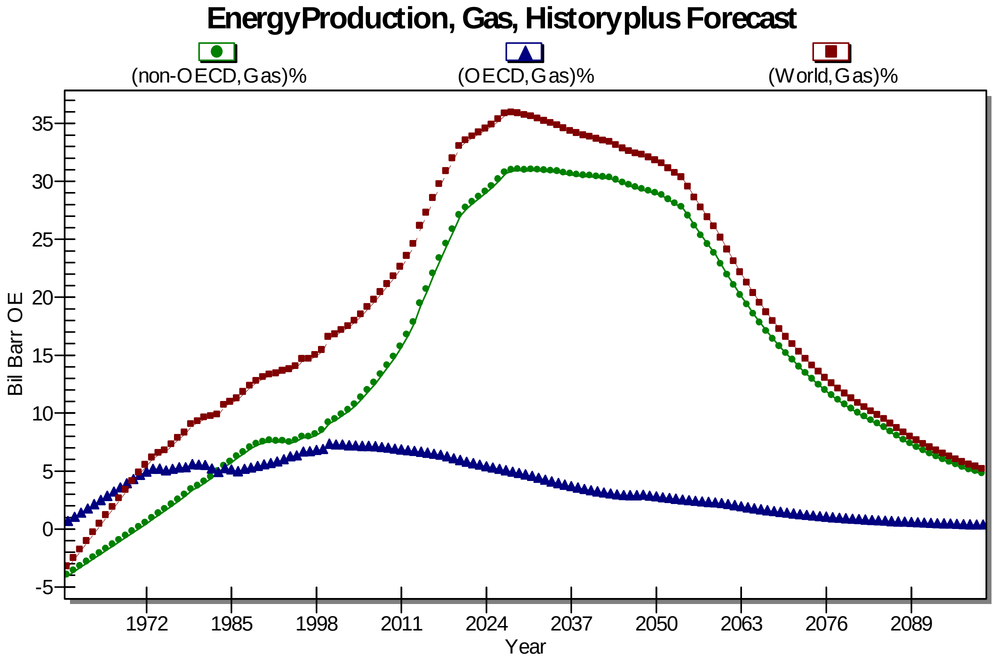


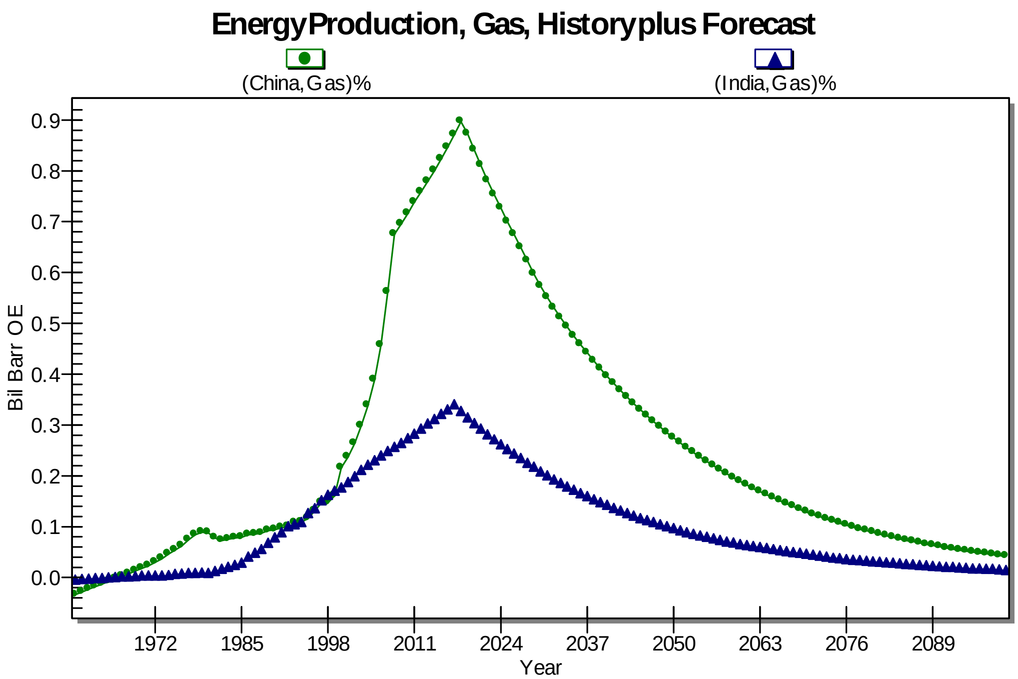


Turning to the supply side, the six graphs below show the historical pattern and IFs base-case forecast for production of oil, natural gas, and coal. The forecasts for production of oil and gas for China and India may initially appear questionable (especially oil and gas in China), because they show run-ups to peak production that are very rapid, followed by collapses. The patterns for the broader country-groupings appear more reasonable, partly because of aggregation of many countries and partly because major oil and gas producers around the world are assigned caps in the base case that dampen such sharp peaks. Note, however, that almost all of the rapid run-up of Chinese oil production is in the historic data. Data on known reserves suggest that such oil production growth is unsustainable and that a peak is almost certain with a fairly sharp decline at least possible. Although China has only started up the production curve shown for gas, the forecast shown is very similar to the historic pattern for Chinese oil.






EnergyProduction, Gas, Historyplus Forecast
(non-OECD,Gas)%
(OECD,Gas)%
(World,Gas)%
Bil Barr OE
35
30
25
20
15
10
5
0
-5
1972
1985
1998
2011
2024
2037
2050
2063
2076
2089
Year


EnergyProduction, Gas, Historyplus Forecast
(China,Gas)%
(India,Gas)%
Bil Barr OE
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
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1972
1985
1998
2011
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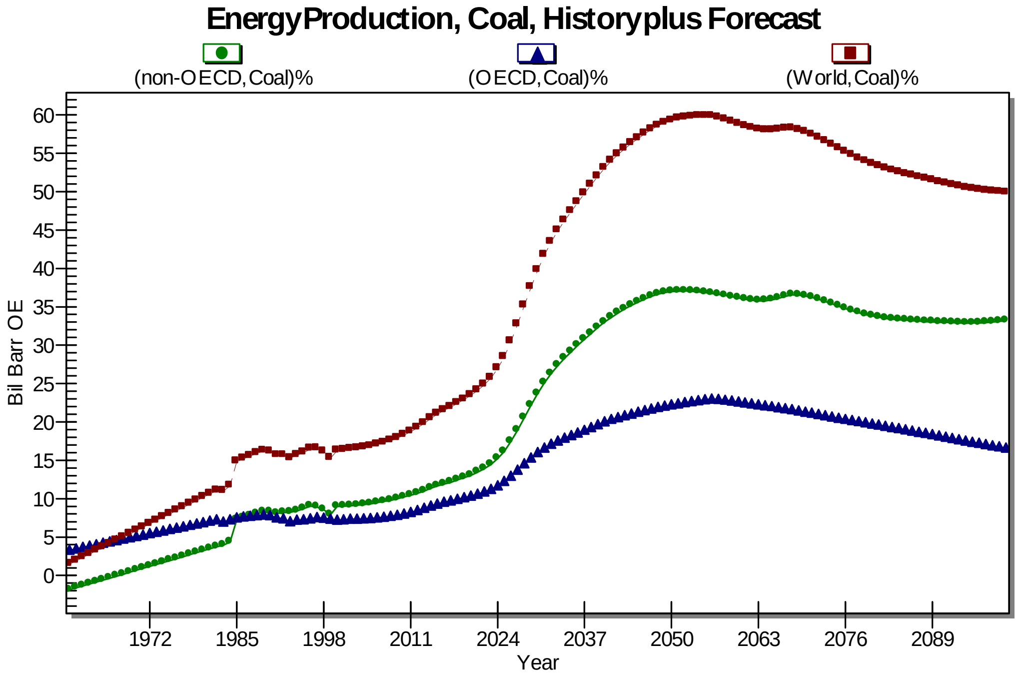
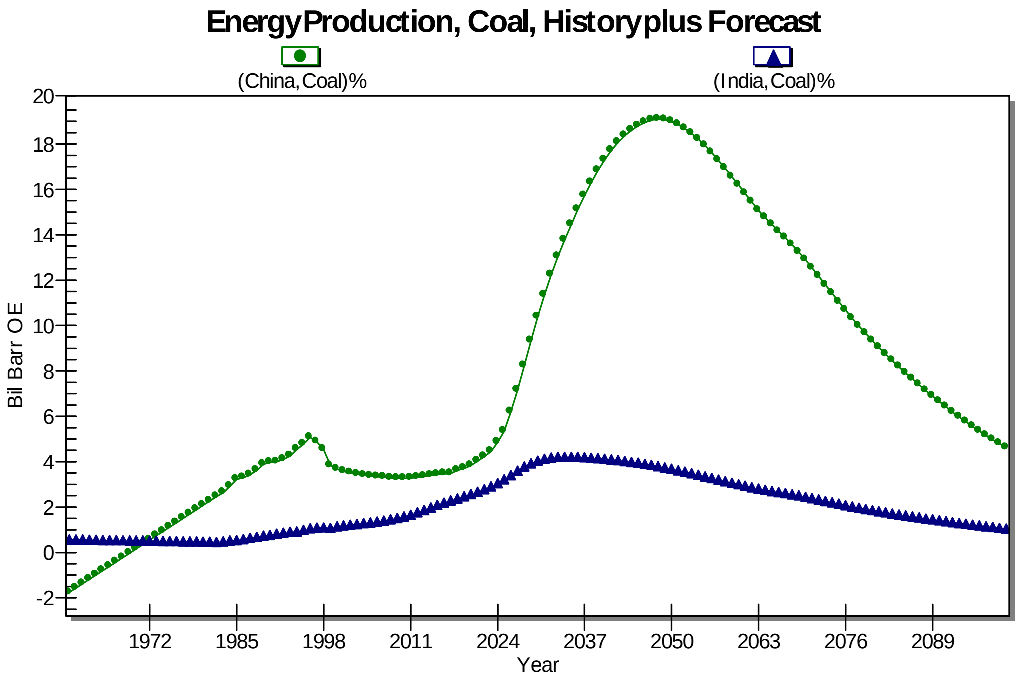
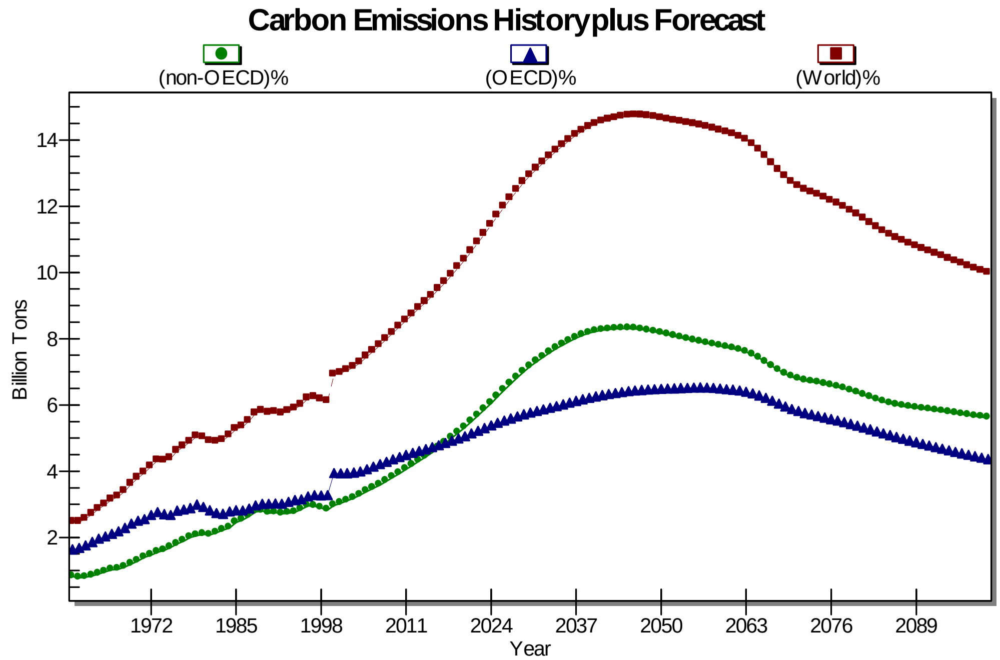
2076
2089
Year

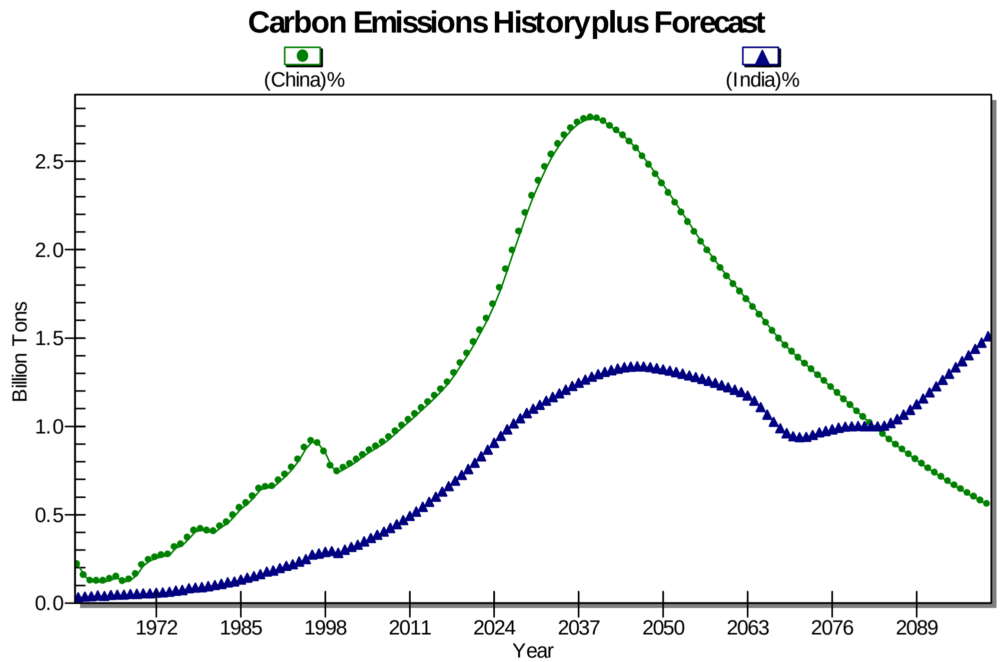




5.5 Environment

The figures below show annual carbon emissions, tied to the consumption (not production) of fossil fuels. The turning points are obviously related closely to the energy demand and supply patterns traced in the previous section.

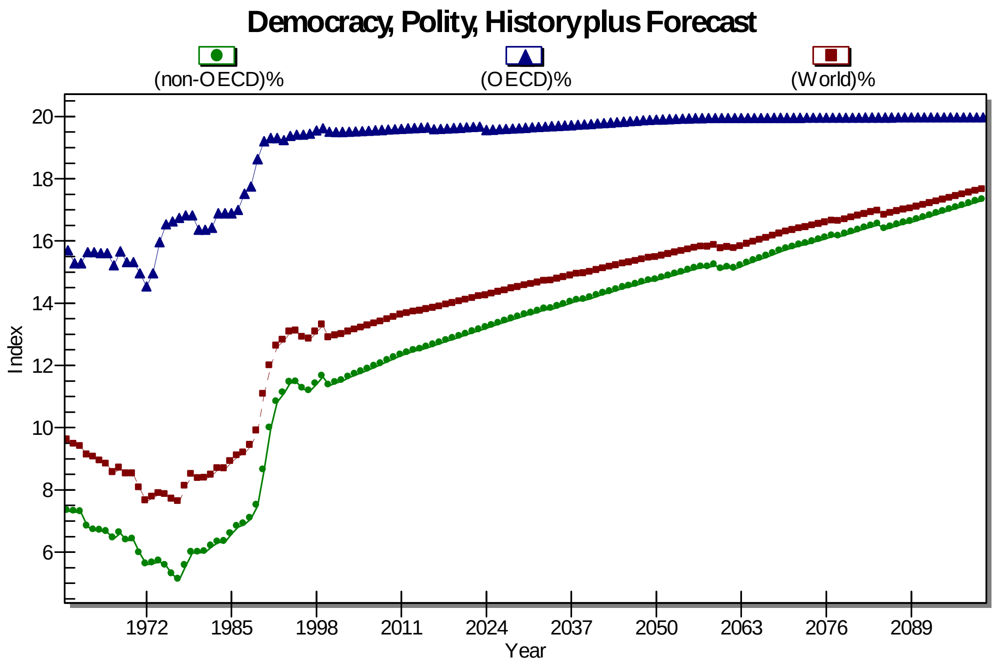


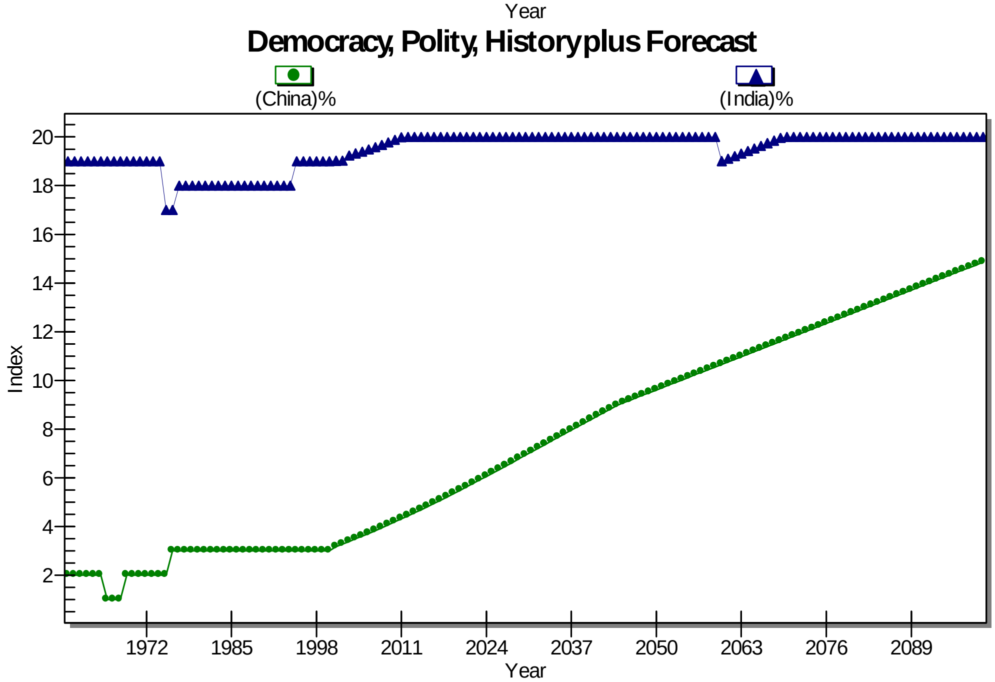


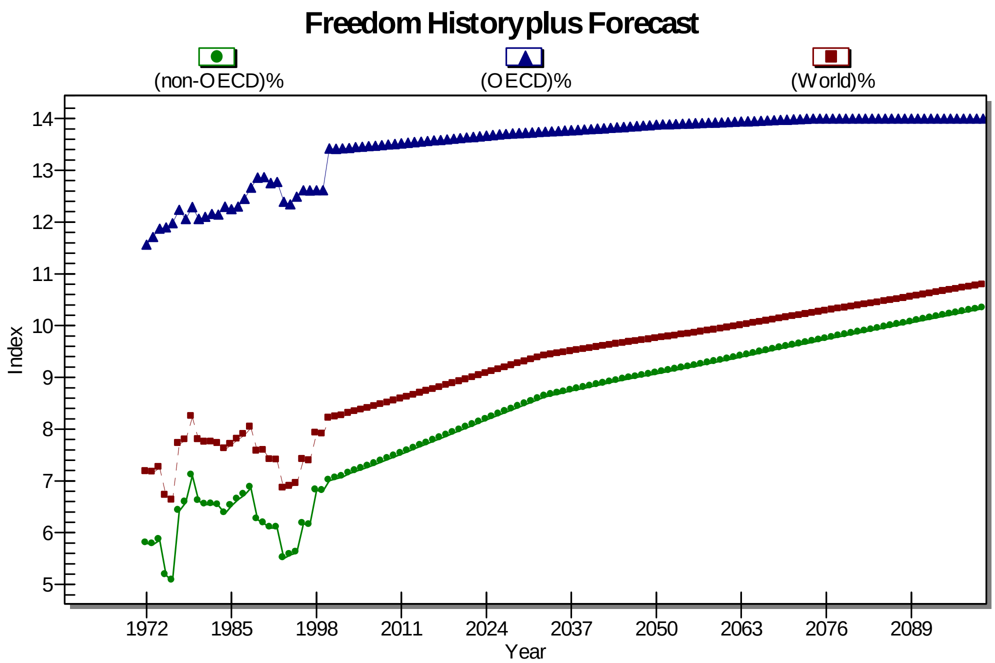
5.6 Socio-Political: Organization and Governance

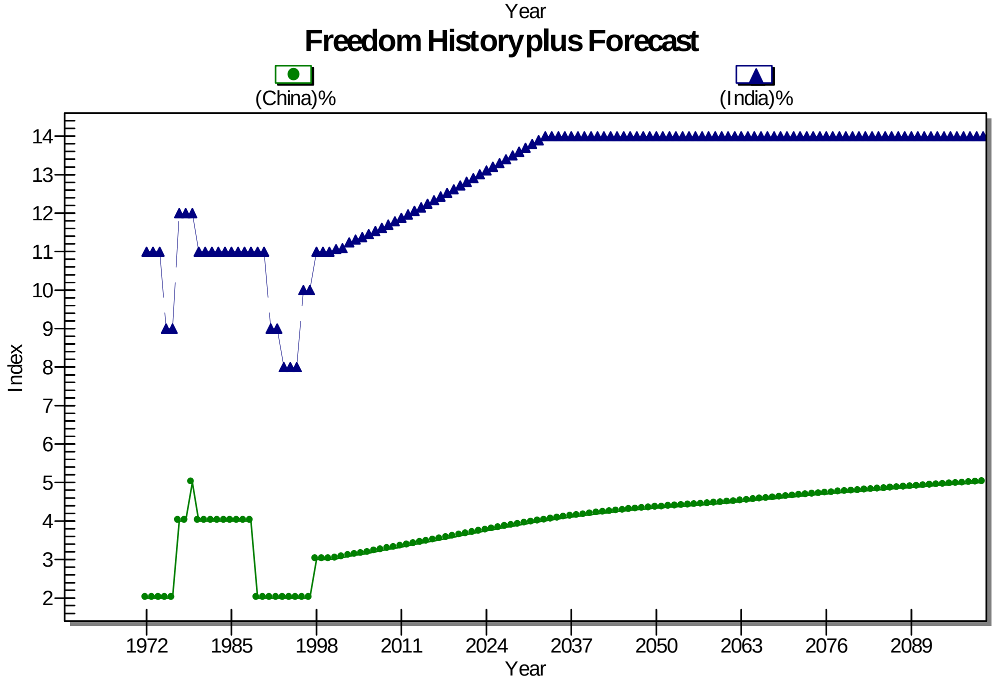
As in the previous chapter, it is useful to sub-divide variables related to socio-political systems. In this case we will look first at those around social organization and governance, then turn to the human condition.

The four graphs below show the Polity project's measure of democracy and the Freedom House's measure of freedom (the sum of its two scales, reversed so that higher numbers are more free). The base case forecasts of IFs fundamentally foresee continued progress towards democracy and freedom, as in past years. The historic pattern clearly includes (at least in the Polity data) the democratic reversal of the 1970s, followed by the third upward wave of the 1980s and 1990s; the forecast does not include waves and links democratization to continued economic and educational advance.

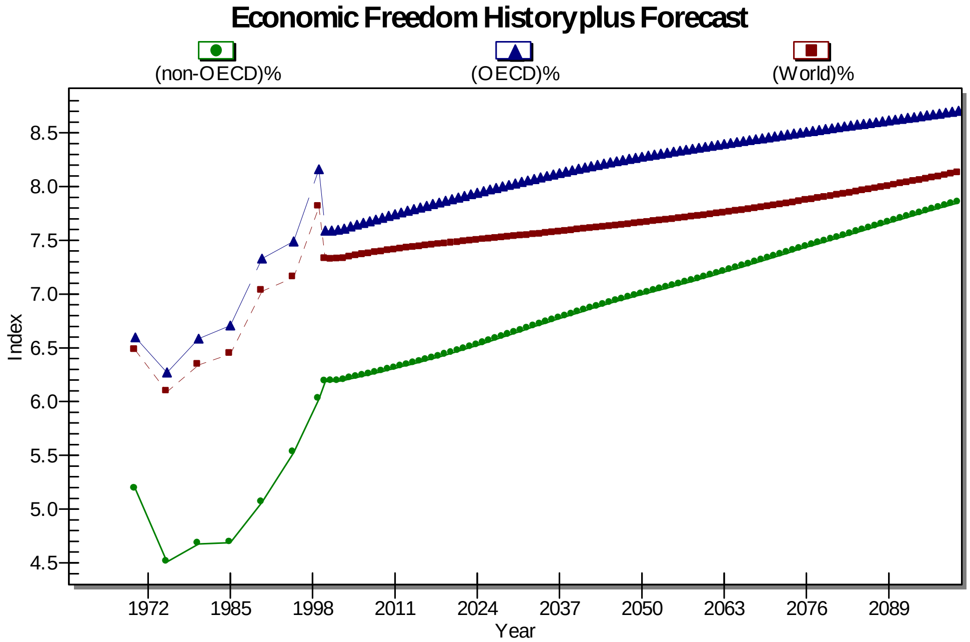


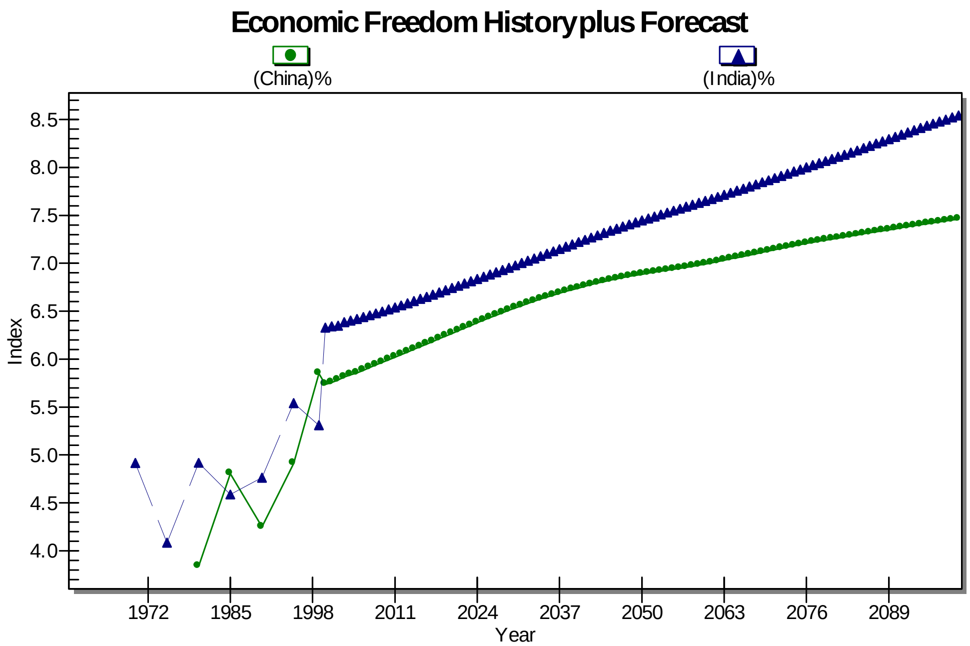






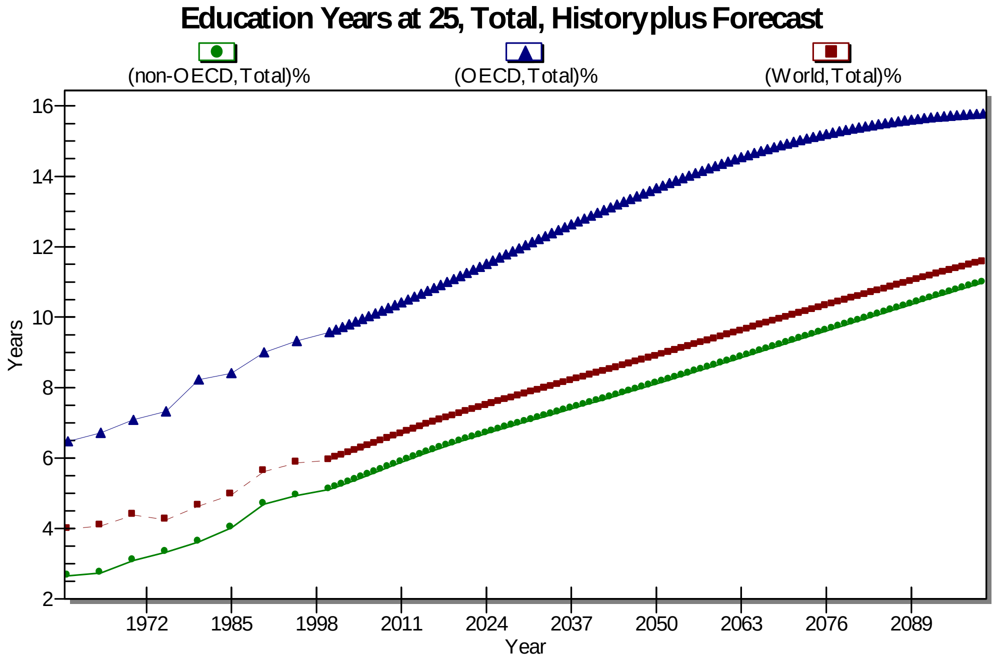
With respect to economic freedom, the two graphs below suggest continued, but slower than historic movement towards economic liberalization. Given the rapid global liberalization of the 1980s and 1990s, associated with the globalization advances of that period, such slowing seems reasonable. This area of forecasting is contentious, not so much in specific forecasts, which scarcely exist, but in prescription and in more general forecasts related to processes of globalization. Economic liberalization is closely related to globalization processes and different observers see continuation of those as desirable or not and as likely or not. A user of the model would do well to treat any forecasts in this area as extremely uncertain.

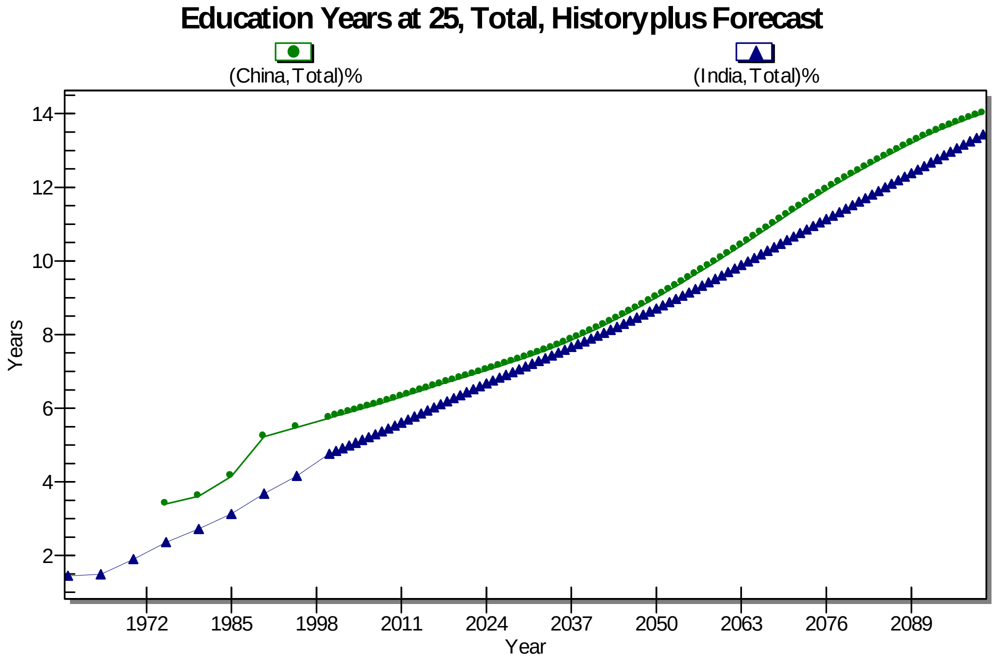




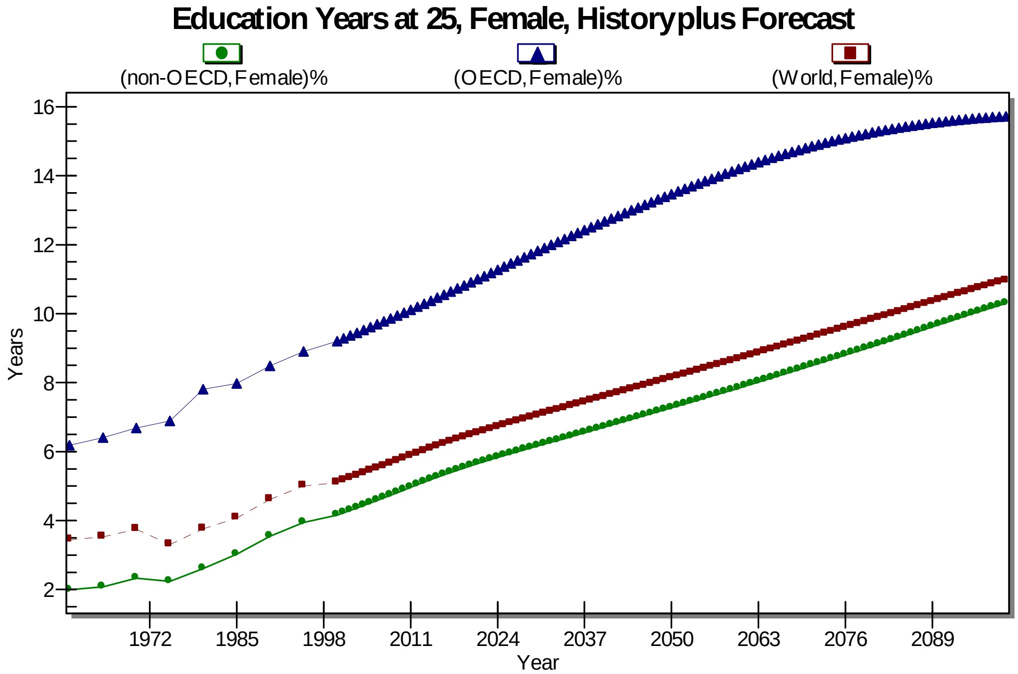
5.7 Socio-Political: Human Condition

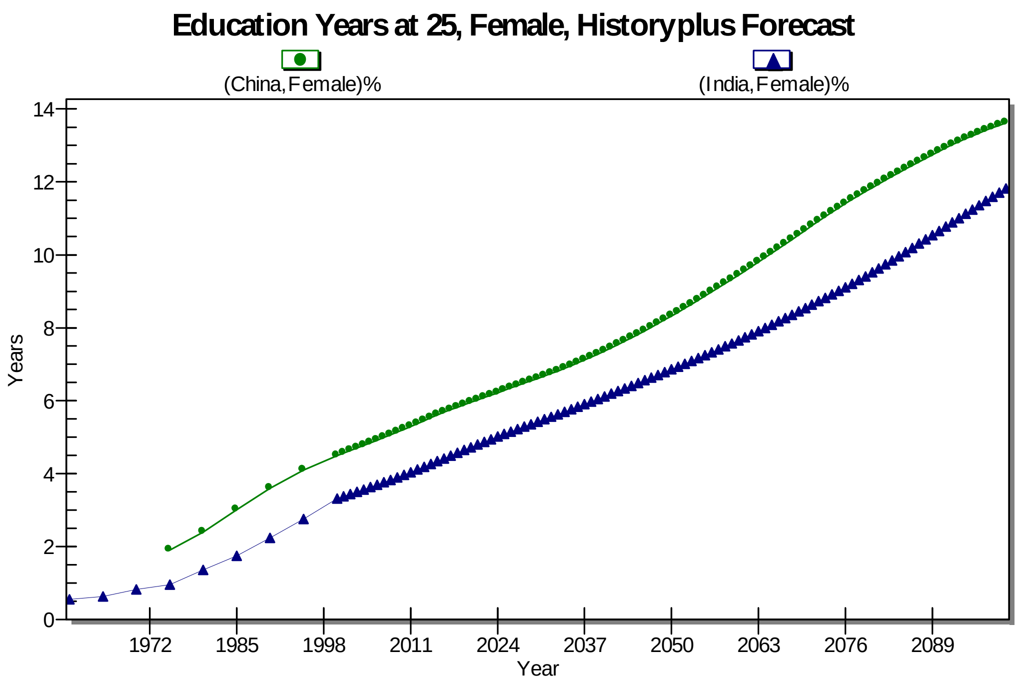
Moving to the human condition, the four graphs below show patterns of change in the average years of education attained by those in populations who have reached at least 25 years of age. The first two show total population and the last two show women only. These numbers have risen rapidly in recent years and there is much reason (including students in the educational and demographic pipelines) to believe that they will continue to rise, although with saturation over the long forecast horizon.



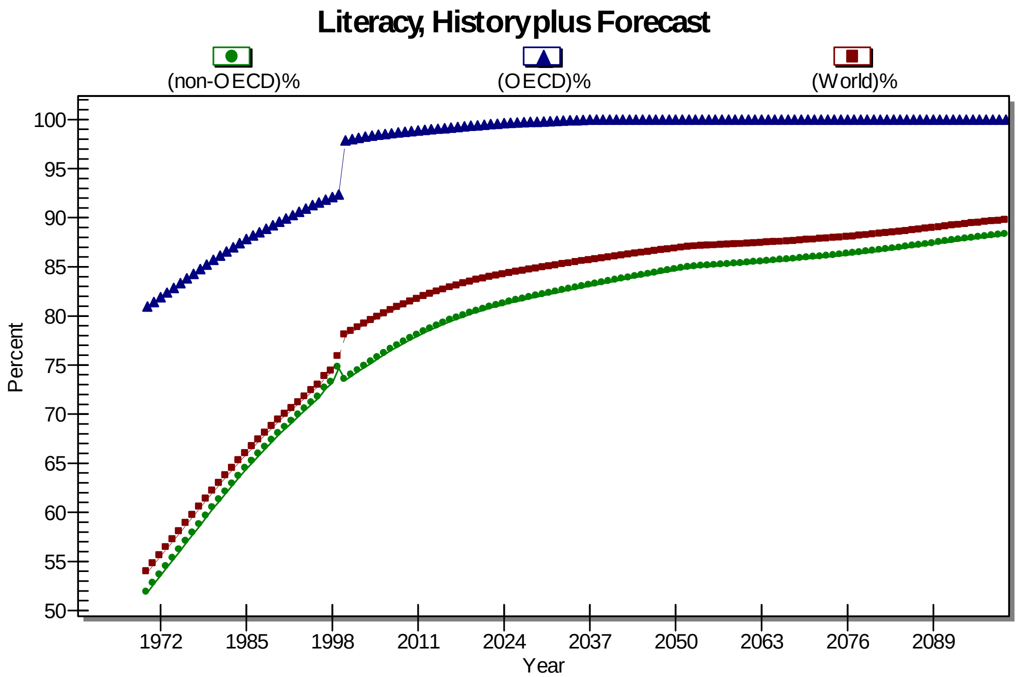


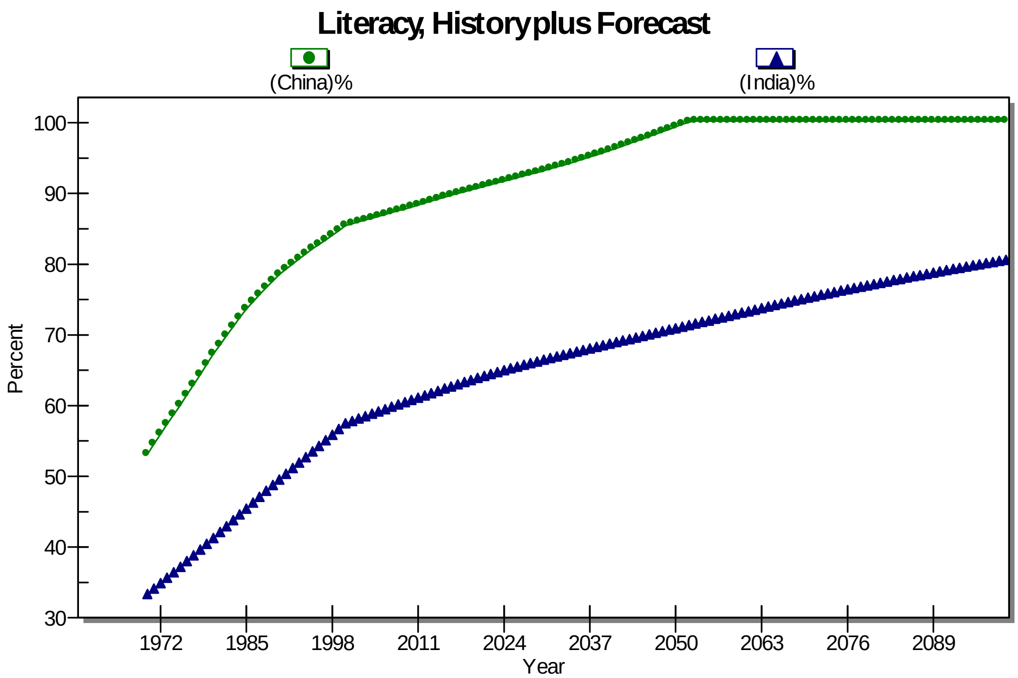
The transients in the figures below, especially those in China and India, will require some attention



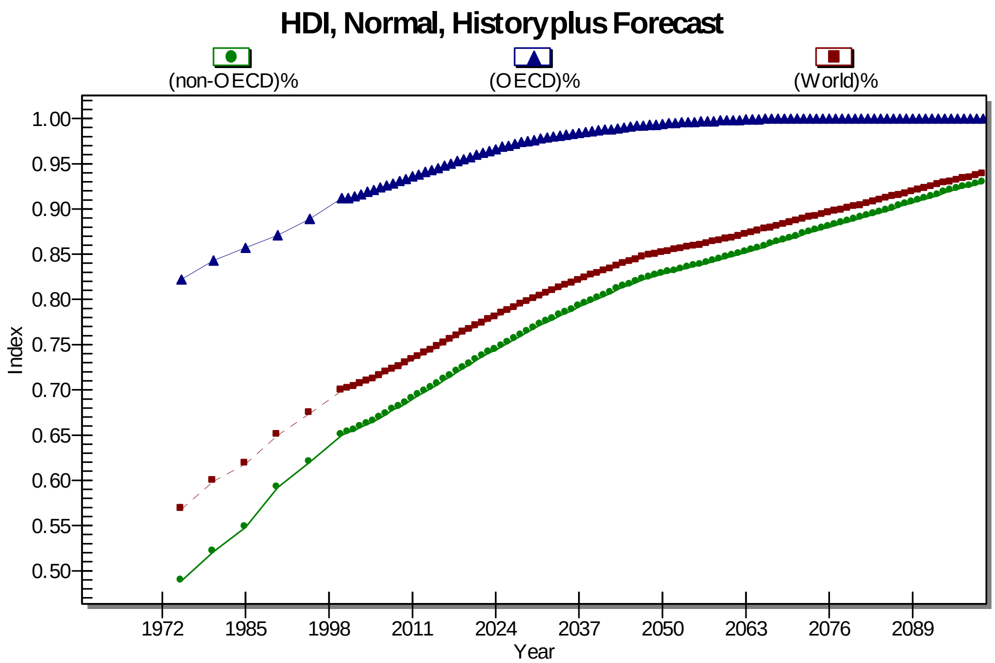


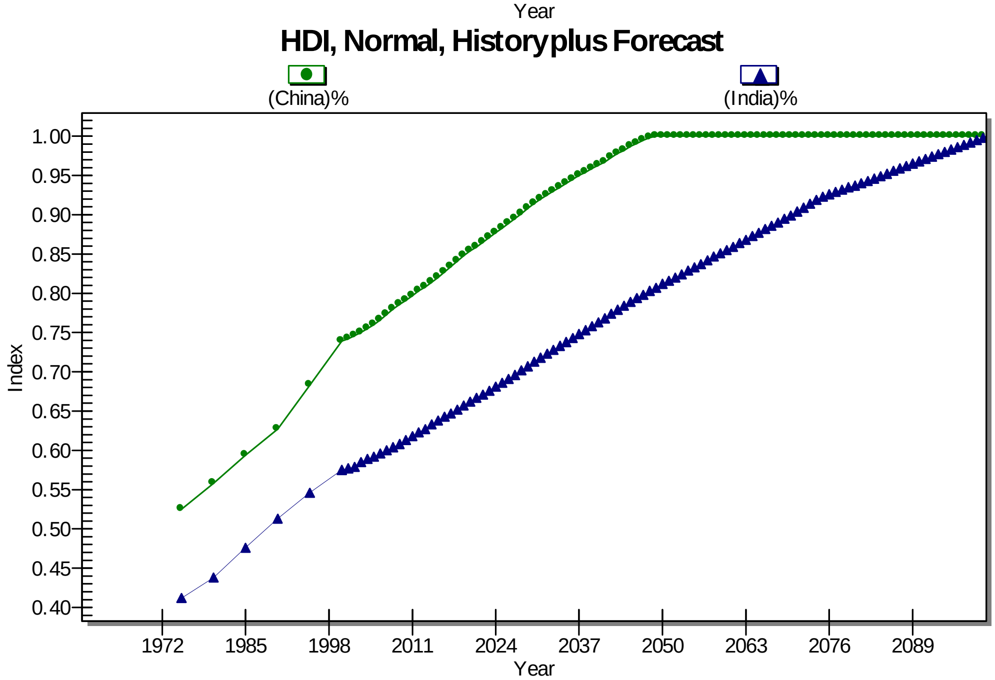
Literacy rates have risen with remarkable speed, especially in developing countries, and saturation effects are certain and underway. In the figure below, the transients occur for OECD countries (which is very unusual, because transients normally indicate missing data for non-OECD countries). The reason is that there are no historic data for many richer OECD countries that have literacy rates near 100% (such as the Canada, Finland, Switzerland, and the United States). Therefore the historic series represents countries such as Mexico and South Korea, while the forecast series represents those countries plus the ones without historic data.





Moving to the very useful summary measure of human development, the human development index (HDI) the graphs below show the rapid historic rise in values, especially for the developing countries, and the saturation effects as the upper limits in that measure are reached (IFs also includes a 21st century version of the measure that does not saturate in this time horizon).





5.8 General Conclusions

All of the long-term forecasts with IFs are surrounded by tremendous uncertainty and therefore subject to great debate. The next chapter will address the issue of alternative assumptions.

The point of this chapter was not to present forecasts that would convince all readers of their likelihood, but to show forecasts that would demonstrate general reasonableness of the IFs base case as a continuation of past patterns, in the face of the most probable limits/constraints/turning points that most observers recognize, and relative to other forecasts in some of the same issue areas. As indicated at the outset, this chapter has not given much attention to the comparison with other forecasts, an effort that merits a paper of its own (see Hughes March 2004, "The Base Case of International Futures (IFs): Comparison with Other Forecasts"). The reader will need judge whether the general forecasts appear credible or not.

6. Testing and Analysis: Interventions

Historic behavior (see Chapter 4) and base case forecasts (see Chapter 5) both provide important information about the credibility of a forecasting model. Most forecasts and analysis with a model, however, rely upon interventions into the model for their real value added, the ability to analyze how the potential application of leverage may influence alternative futures.

Sensitivity analyzes are often done with models, especially relatively simpler ones, to explore behavior with interventions. The purpose of the sensitivity analysis is often to search for strategies that might suggest useful action in the pursuit of goals. A significant extension of such capabilities is the use of software that can search across a wide set of levers of intervention for combinations of intervention that either identify optimizing strategies (as with the traditional linear programming techniques and well-specified models) or suggest robust, satisficing strategies (a more appropriate approach for less well-specified models of complex systems of human behavior). For instance, the Computer Assisted Reasoning System (CARS) was constructed for the latter type of analysis (see Lempert, Popper, and Bankes 2003).

The more fundamental and complicated question, however, is not what interventions produce in a model, but whether what they produce is credible. That is, unfortunately, also a question that in substantial part is unanswerable. If we knew what interventions should produce, we presumably would not need to spend vast amounts of time developing the model. The purpose of such investment is to help us think about what interventions might produce in a real world system and why.

So what *should* we ask of models with respect to interventions? The following list may be helpful:

1. Ability to let the user intervene widely and flexibly, both with individual interventions and with combinations of them.

2. The structuring of interventions so that they either (1) frame uncertainties in the system's specification, (2) relate directly to actions that might be taken in the real-world system of interest or (3) reasonably reflect more aggregate patterns of change that combinations of human actions could help bring about.

3. The mechanical control of interventions such that they do not exceed outer ranges of reasonable uncertainty or potential human action and so that they do not cause blow-ups of the model.

4. Specification of formulations and parameters consistent with data and theory, providing some confidence that parametric interventions will produce reasonable behavior

5. Sufficient experimentation or "playing" with the model, with results reviewed by the eyes of many domain experts, so that behavior in the face of individual interventions and packages of them have considerable face validity.

With respect to the first item on this list of desired features, the interface of the IFs model allows the user full control over all parameters and initial conditions. This includes the control of parameter variation over time, essential for the phasing in or out of interventions.

With respect to the second item, the philosophy of IFs builds has led to the structuring of interventions around key technological and environmental uncertainties, on one hand, and human agency on the other. The modeling approach in IFs is called "structure-based, agent-class modeling." Households, firms and governments are the agent classes specified. In a large-scale global model, it is very often impossible to structure interventions at the detailed level of specific human agency, such as government policies to create agricultural extension services. Instead, a multiplier to increase crop yields may need to be the more aggregate pattern that the model can make available to its users.

With respect to the third item, no model is invulnerable to blow-ups or crazy results. The system has, however, been made very robust through years of experimentation.

Concerning each of these first three desiderata, see Hughes (July 2004, "Scenario Analysis with International Futures"). With respect to the fourth item, Chapter 3 provided information on the documentation of IFs, allowing conceptual, theoretical, and empirical analysis of it.

It is the fifth item, the experience with analysis using the model, that this chapter addresses. It explores some of the results of scenario building with IFs, in efforts that have looked at both individual interventions and the interactions of interventions (their synergistic effects, trade-offs, and contradictions).

Specifically, the chapter draws from and comments on four analysis projects. The first was the TERRA project, sponsored by the European Commission, with special attention to prospects for using the ICT-based economy to support transition to sustainable development. The second was the 2020 project of the U.S. National Intelligence Community (NIC), with a focus on the global security environment. The third is the fourth Global Environmental Outlook (GEO-4) of the United Nations Environment Programme (UNEP), with interest in long-term global environmental scenarios. The fourth, sponsored by Frederick Pardee, is a project to create a Human Development Report plus 50 focused on global poverty reduction and more general improvement of the global human condition.

6.1 European Commission: TERRA Project

For more information on the use of IFs in the TERRA project, see Hughes and Johnston (2005), which is a reduced version for publication in *Futures* of a larger project analysis. In that article, the following specific interventions were identified as consistent with many of the policy prescriptions and even the specific targets of declarations issued by the European Commission:

- **Increased investment in R&D**. An increase for OECD countries of 50% relative to the base-case (an increase from 2% to 3% of GDP in the EU, as agreed at the "Barcelona Summit" in 2002), phased in over 15 years, and an increase for non-OECD countries of 100%, phased in over 15 years.

- **Increased diffusion of electronic networking.** A 50% increase relative to the base-case for non-OECD countries, phased in over 15 years, and achieved by the pursuit of National "e-strategies" as envisaged at the WSIS, and modelled on the eEurope Action plan in the EU. EU network access accelerated to 90% coverage by 2015, in a follow-up to the eEurope Action Plans. US rates are at endogenous levels.

- **Greater investment in formal education**. A 50% increase in investment relative to the base-case over 15 years for non-OECD countries and 20% increase for OECD countries, both applied to the base percentages (i.e., a 20% increase in a 5% investment rate yields a 6% rate).

- **Greater investment in health care**. A 50% increase relative to the endogenous base-case over 15 years for non-OECD countries and a 20% increase for OECD countries.

- **Increases in official development assistance (ODA).** Growth over 15 years to 0.45% of GDP for the EU, to 0.25% for the USA, and to 0.5% for other OECD countries. These rates are below the 0.7% U.N. target, but are perhaps more likely.

- **Trade and general economic liberalisation.** A 50% reduction in world-wide tariffs and non-tariff trade barriers over 15 years and further liberalisation of economies realising a 20% increase in the economic freedom index.

- **Support for faster "environmental technology" development.** We specifically assume this can result in a 20% increase in crop yields per hectare relative to the already increasing yields of the base-case; a 50% faster cost-reduction for renewable energy (from 1.0% per year to 1.5% per year) over 15 years and maintenance at the higher rate thereafter, and faster improvement in energy efficiency (energy use per unit GDP) by 50% over 50 years.

- **Carbon taxes.** Phasing in of costs for carbon dioxide emissions of $200 per ton in OECD countries and $50 per ton in non-OECD countries, over 15 year periods, through increasingly tight and inclusive “cap and trade” frameworks.

Collectively, the interventions created a “Sustainability Scenario.” The results of the interventions, individually and collectively were collated in the two tables reproduced below:

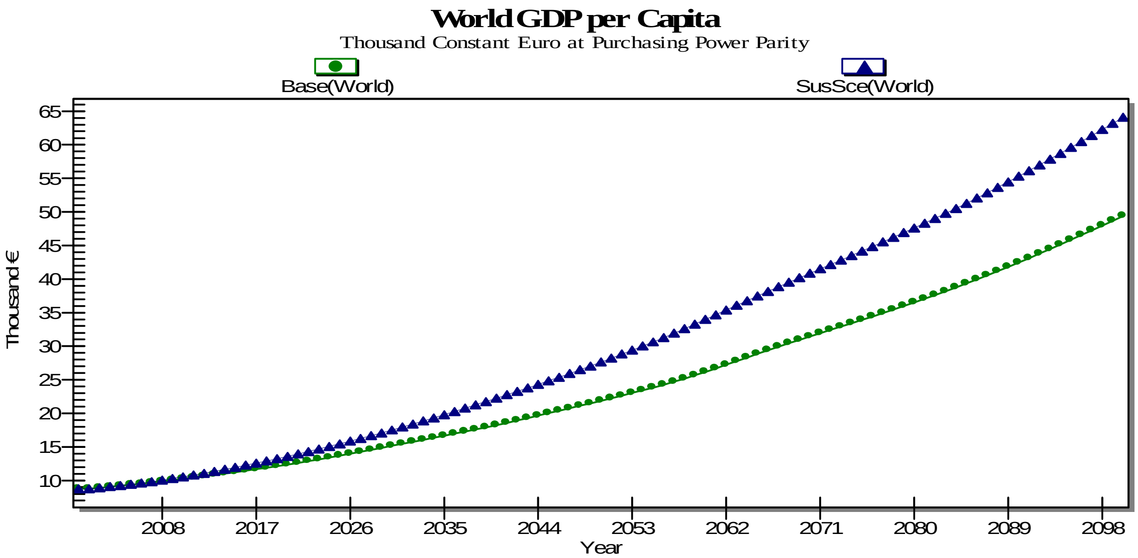
	Years of Education (at Age 25)			Human Development Index (HDI)			GDP per capita at PPP (Thousands)		
	EU	Non-OECD	World	EU	Non-OECD	World	EU	Non-OECD	World
Base Case									
2000	8.70	4.83	5.70	0.917	0.666	0.712	21.84	4.86	8.42
2050	12.51	7.28	8.01	0.990	0.830	0.853	42.09	15.32	19.73
2100	14.72	10.41	10.97	1.048	0.965	0.978	75.13	34.56	42.38
R&D									
2050	12.52	7.30	8.02	0.991	0.832	0.855	42.42	15.98	20.33
2100	14.73	10.47	11.02	1.049	0.970	0.983	77.05	38.42	45.93
Networking									
2050	12.52	7.30	8.03	0.991	0.833	0.855	45.71	17.40	21.84
2100	14.72	10.47	11.02	1.048	0.967	0.980	83.23	43.06	50.00
Education									
2050	12.58	7.24	8.30	0.991	0.846	0.876	47.49	19.40	26.00
2100	14.76	10.26	11.00	1.050	0.970	0.987	80.96	45.85	53.85
Health									
2050	12.50	7.27	8.00	0.993	0.833	0.856	45.49	17.09	21.55
2100	14.71	10.41	10.97	1.051	0.967	0.981	82.97	42.02	49.20
Investment									
2050	12.55	7.44	8.15	0.990	0.841	0.863	47.02	18.23	22.77
2100	14.75	10.63	11.16	1.049	0.971	0.983	83.97	43.98	50.91
ODA									
2050	12.57	7.33	8.05	0.991	0.832	0.855	45.50	17.12	21.60
2100	14.72	10.48	11.03	1.048	0.967	0.980	82.80	42.40	49.42
Trade									
2050	12.51	7.28	8.01	0.991	0.830	0.853	45.81	17.08	21.59
2100	14.70	10.41	10.97	1.048	0.965	0.978	84.13	42.31	49.44
Env Technology									
2050	12.53	7.39	8.11	0.993	0.839	0.861	47.08	18.20	22.77
2100	14.75	10.63	11.16	1.049	0.971	0.984	85.15	44.15	51.27
Carbon Tax									
2050	12.50	7.26	8.01	0.990	0.832	0.855	45.54	17.23	21.72
2100	14.71	10.45	11.00	1.048	0.965	0.978	82.58	42.04	49.00
Combined									
2050	12.61	7.75	8.42	1.000	0.870	0.888	51.38	22.86	27.29
2100	14.84	11.17	11.63	1.056	0.993	1.003	93.22	57.58	63.74

TERRA Table 2. Impact of Policy Interventions on Human Development and Economic Growth

	GDP/P (1000s) NS Ratio	Democracy (Polity Measure) EU	Non-OECD	World	Carbon Emissions (Billion Tons) EU	Non-OECD	World	Global Forest	Global CO2 PPM
Base Case									
2000	22.29	19.62	14.12	16.53	0.992	3.316	6.647	4166.0	371.9
2050	9.09	19.94	16.85	18.20	0.343	10.060	11.780	3822.0	561.7
2100	4.85	19.97	18.74	19.28	0.007	4.414	4.420	4124.0	660.0
R&D									
2050	8.68	19.94	16.86	18.21	0.330	10.230	11.890	3811.0	564.5
2100	4.38	19.97	18.74	19.28	0.007	4.498	4.505	4071.0	668.0
Networking									
2050	8.84	19.94	16.87	18.21	0.335	10.150	11.840	3814.0	563.4
2100	4.68	19.97	18.75	19.28	0.007	4.336	4.343	4112.0	663.3
Education									
2050	7.88	19.96	17.03	18.30	0.495	9.501	11.520	3873.0	559.1
2100	4.04	19.98	18.79	19.30	0.014	4.001	4.014	4107.0	649.6
Health									
2050	9.09	19.94	16.85	18.20	0.343	10.060	11.780	3822.0	561.7
2100	4.85	19.97	18.74	19.28	0.007	4.414	4.420	4124.0	660.0
Investment									
2050	8.44	19.94	16.94	18.25	0.309	10.160	11.680	3782.0	569.8
2100	4.57	19.97	18.76	19.29	0.007	4.286	4.293	4111.0	666.7
ODA									
2050	9.02	19.94	16.89	18.23	0.341	10.080	11.800	3822.0	562.1
2100	4.78	19.97	18.75	19.28	0.007	4.405	4.411	4121.0	661.7
Trade									
2050	9.10	19.94	16.85	18.20	0.336	10.090	11.800	3810.0	562.5
2100	4.87	19.97	18.74	19.28	0.023	4.425	4.447	4128.0	659.3
Env Technology									
2050	8.55	19.94	16.94	18.25	0.224	7.035	8.048	4061.0	503.3
2100	4.64	19.97	18.77	17.30	0.013	3.987	3.910	4411.0	560.7
Carbon Tax									
2050	8.96	19.94	16.87	18.21	0.349	9.777	10.940	3855.0	530.2
2100	4.83	19.97	18.74	19.28	0.007	4.269	4.274	4208.0	619.3
Combined									
2050	6.75	19.94	17.17	18.38	0.182	7.495	8.040	4045.0	496.8
2100	3.53	19.97	18.82	19.32	0.026	3.630	3.660	4403.0	559.6

TERRA Table 3. Impact of Policy Interventions on Global Equity, Democracy and Environmental Sustainability

The combined package of the Sustainability Scenario led to the following growth of global GDP relative to the base case.



TERRA Figure 4. World GDP per Capita in the IFs Base Case and the Sustainability Scenario.

To repeat, there is no independent referent against which to judge these results with IFs. It is important to allow domain experts full access to the results of individual and combined interventions and to the structure of the model.

6.2 National Intelligence Council: Project 2020

For more information on the National Intelligence Council's 2020 Project see United States National Intelligence Council (2004). *Mapping the Global Future*. For more information on the scenario analysis of IFs for the project, see Hughes (October 2004), "2020 Project: IFs Scenario Implementation." The 2020 Project was heavily built around four scenarios: Davos World, Pax Americana, A New Caliphate, and Cycle of Fear.

Davos World is powered by strong and healthy globalization. More specifically, it is driven by continued liberalization and growth in trade, investment, and population flows internationally and by economic and political liberalization domestically. It is also a world that benefits from technological advance that diffuses rapidly across the global system. The advances in technology help address many problems, including tightness in the energy market and the well-being of the world's most disadvantaged. The interventions made to implement it in IFs were:

Economic

- Trade liberalization (agriculture, manufactures, services) lowers effective prices of traded goods by another 10% by 2010, relative to the base case.

- FDI flows increase by 50% relative to the base case. This is accomplished by 2010 and remains in place.

- Rates of convergence of productivity to the US level rise globally by a further 0.25% in 2010 and remain at that level.

Demographic

- Global immigration rises by 50% relative to the base case over 10 years and remains at the higher level through 2020.

Socio-Political

- Domestic economic liberalization accelerates with global liberalization, leading to values on the 10-point economic freedom scale of the Fraser Institute that are 20% higher in 2020 than in the base case.

- Democracy advances accelerate on both the Polity and Freedom House measures, leading to values in 2020 that are about 10% more democratic on both scales.

Technology

- Technology driving the efficiency of energy use reduces demand for energy per unit of GDP by a further 0.5% per year (on top of about a 1.0% long-term average in the base).

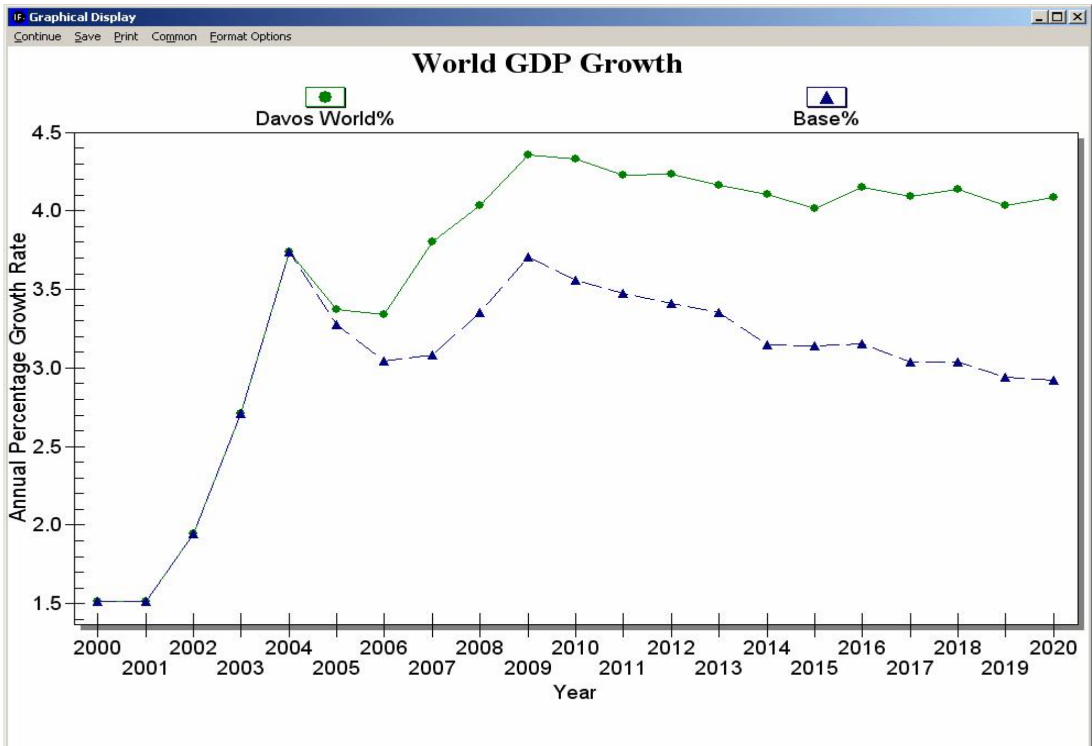
- Rates of discovery of oil and gas increase by about 50% relative to the base case (although initial known reserves and ultimate recoverable resources are not changed and could be argued to also increase somewhat with technological advance).

- Rates of production of natural gas rise steadily relative to the base case and climb 50% higher (where the reserve base permits) by 2020.

- Rates of production for new renewable energy forms (e.g. wind and photovoltaic but not hydro) begin to rise steadily and by 2020 are 4 times those of the base case.

- Rates of growth in agricultural yields in Sub-Saharan Africa begin to climb steadily relative to the base case and are 30% higher by 2020.

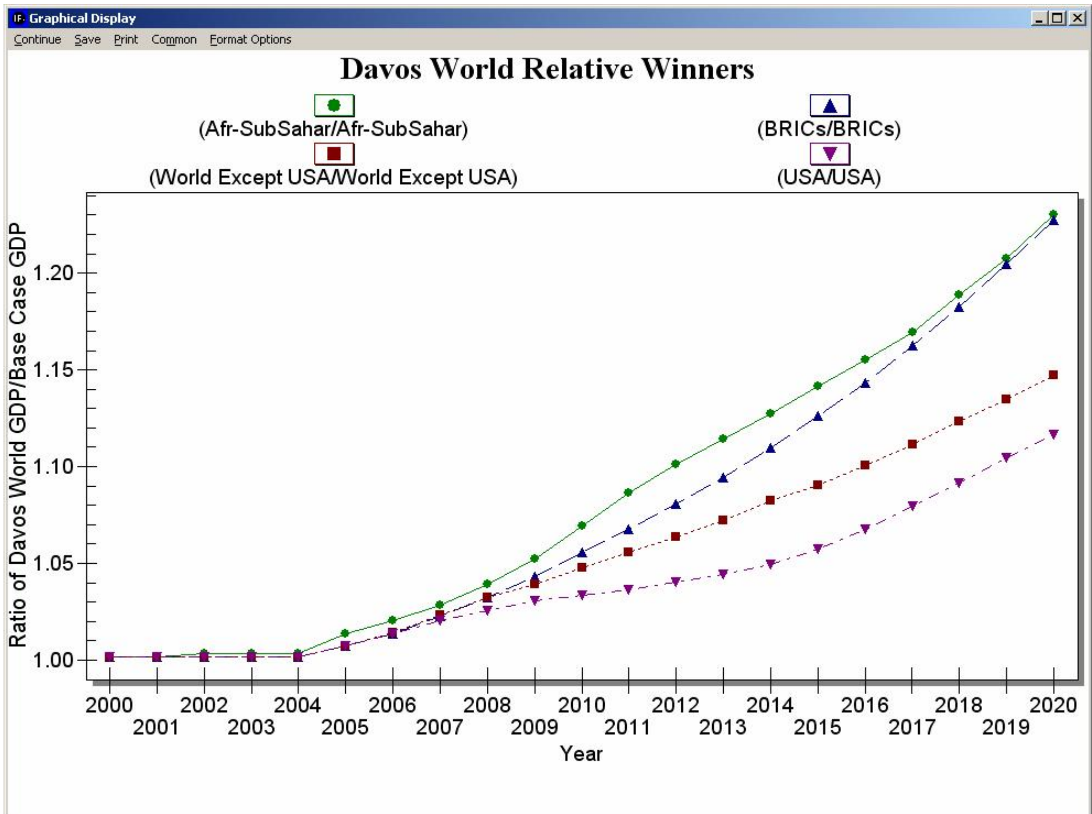
Among the results of the interventions for the Davos World interventions was an increase in global economic growth to an average of about 4% through 2020. The assumptions about technological diffusion throughout the system and the various liberalizations drive this result. Such a growth rate is at the very high end of likely global futures. For comparison, in the base case growth rates erode somewhat towards about 3% by 2020, reduced in significant part because of slowing population growth.



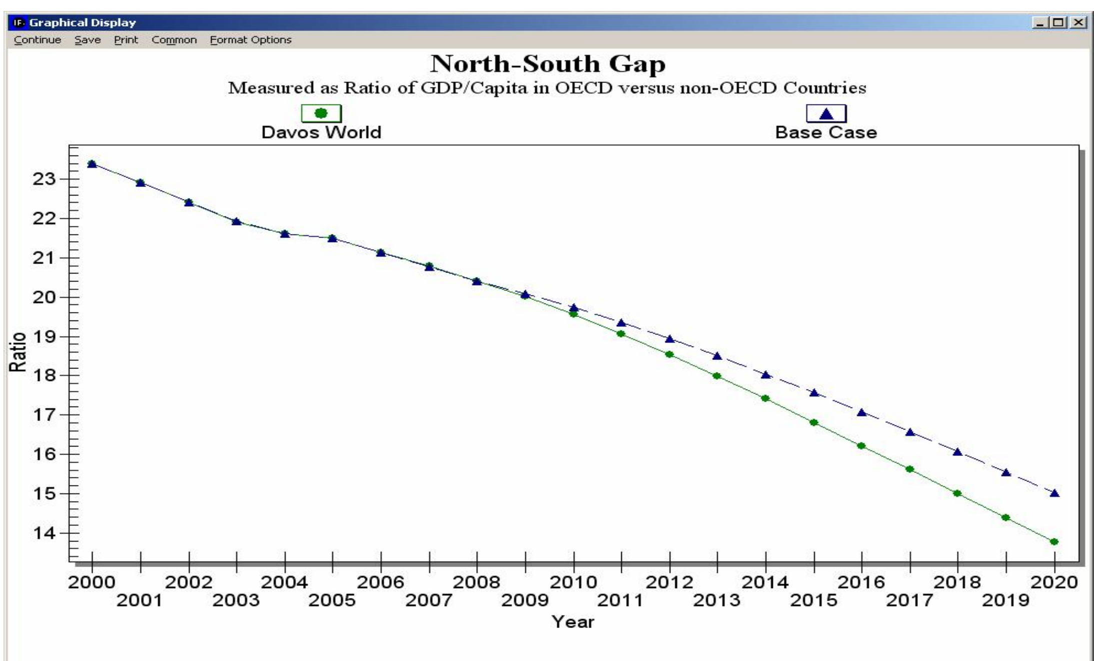
Essentially all regions benefit from the Davos World. *But in all scenarios, some countries and regions benefit or lose more than others.* Looking at GDP over time relative to the base case (see below) helps us see the differential impact.

In the Davos World, the BRICs (Brazil, Russia, India, and China) and other trade-oriented emerging countries do especially well. So does Sub-Saharan Africa, for which the assumptions of the scenario about advance in agricultural yields, perhaps driven by success against OECD subsidies in the Doha round, are especially important. The world as a whole outside of the United States does reasonably well, gaining about 12% in GDP relative to the base case.

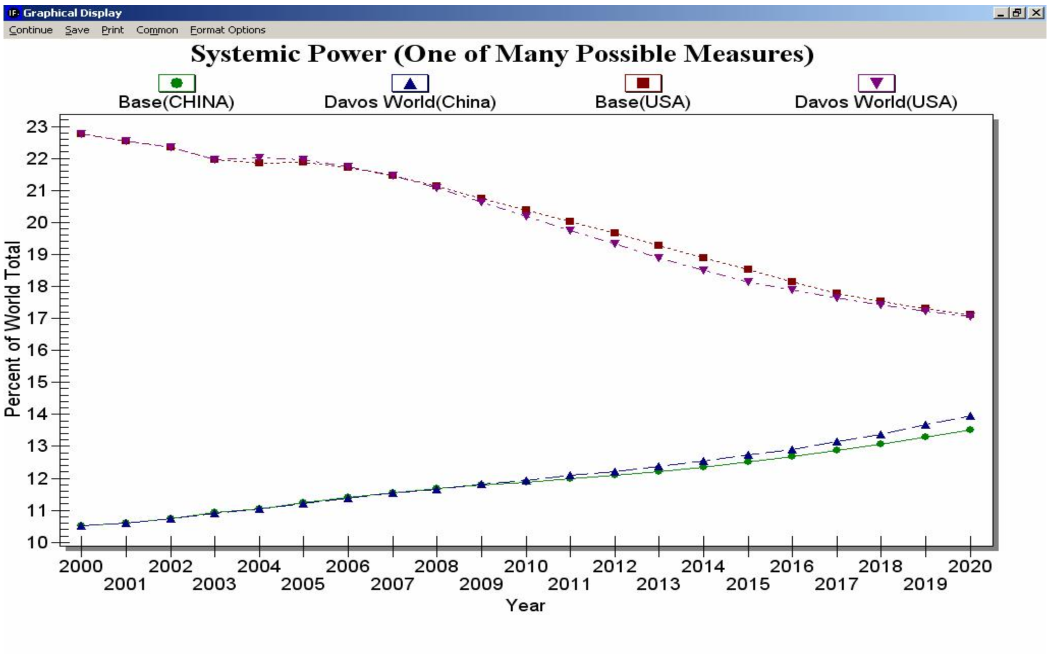
As technology diffuses rapidly around the world, the US, as technological and economic leader, does well compared to the base case, but not as relatively well as the rest of the world. It is useful to recognize that this is a world of absolute gains for the US, but at the same time it is characterized by relative loss of position.



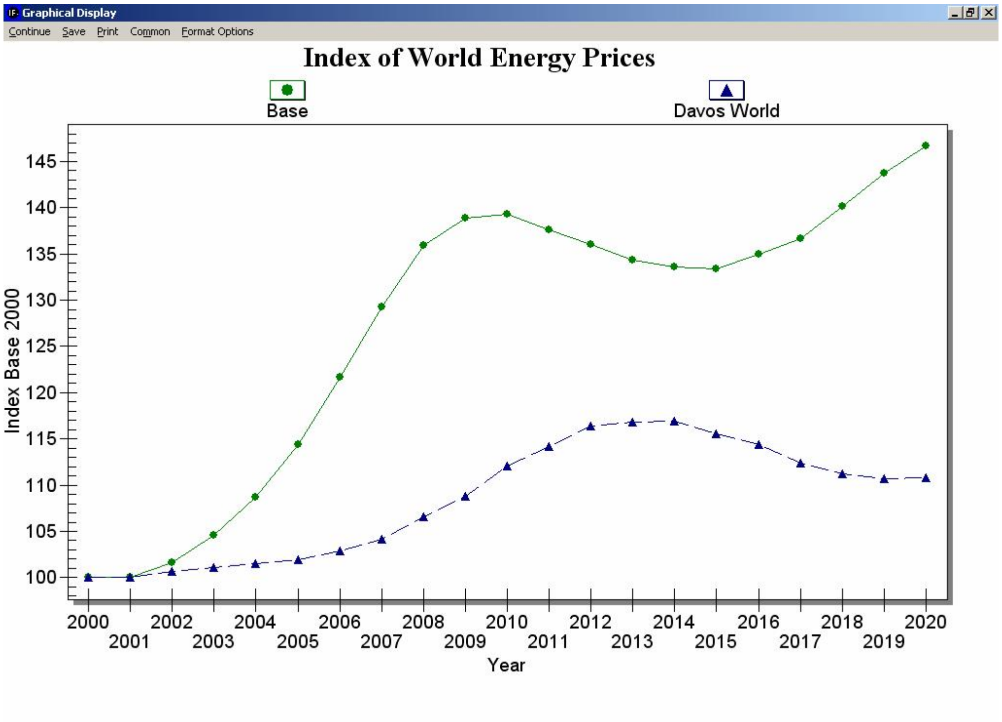
Continuing the exploration of absolute and relative gains, the figure below shows the North-South gap in the Davos World scenario relative to the base case. It is narrowing in both cases, but more quickly in Davos World, as technological capability and economic growth flows to developing countries.



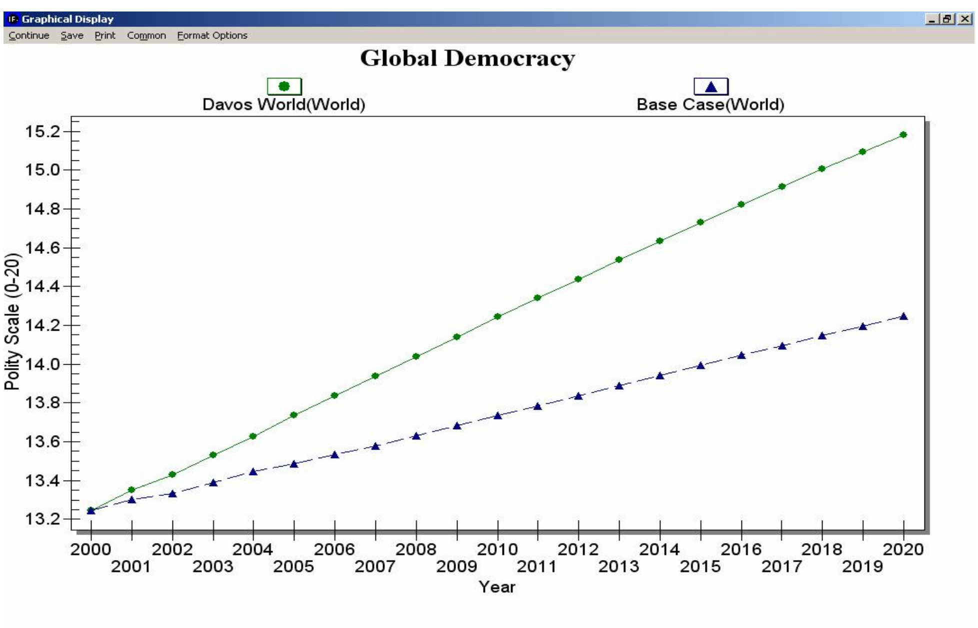
Continuing with the theme of relative position, the figure below shows one of many possible measures of power within the global system, drawing on economic size, economic development level, population size, and military spending as the component elements. In the base case China significant narrows the gap with the US by 2020 and in Davos World the gap closes slightly more.



The base case of IFs shows energy prices growing significantly, mostly in this decade. In the Davos World global energy prices are relatively flat through 2020, in spite of higher economic growth. The immediate drivers of this result in the scenario are technological, namely greater efficiencies in energy use and faster discoveries of oil and gas.

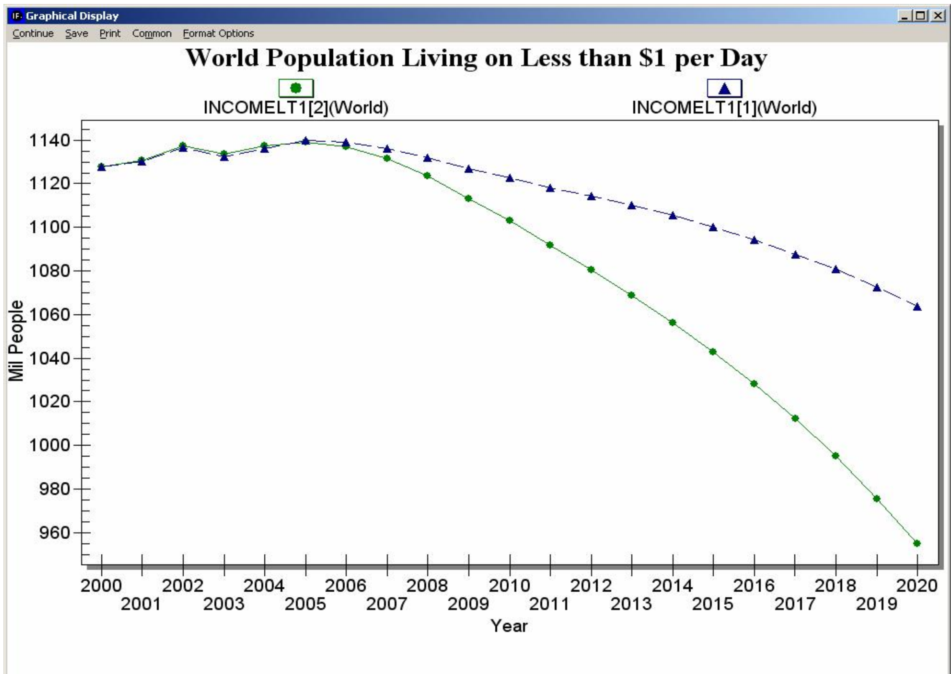


Democracy advances more rapidly in Davos World, continuing the impetus of the Third Wave.



The number of people globally living on less than $1 per day declines somewhat in the base case, but the decline gains momentum in Davos World. This measure indicates progress towards what is almost certainly the foundational Millennium Development

Goal, namely the reduction by ½ in the proportion of the world's population living in absolute poverty.



Anyone interested in learning about the interventions tested for the other four scenarios or their results should see Hughes (October 2004). In addition, the NIC scenarios are available for further analysis on the IFs web site (www.ifs.du.edu).

6.3 United Nations Environment Program: Global Environment Outlook-4

For information on UNEP's third Global Environment Outlook see UNEP (2002). For more details on the IFs scenario implementation see Hughes (June 2005). The GEO-4 is scheduled for release in 2007.

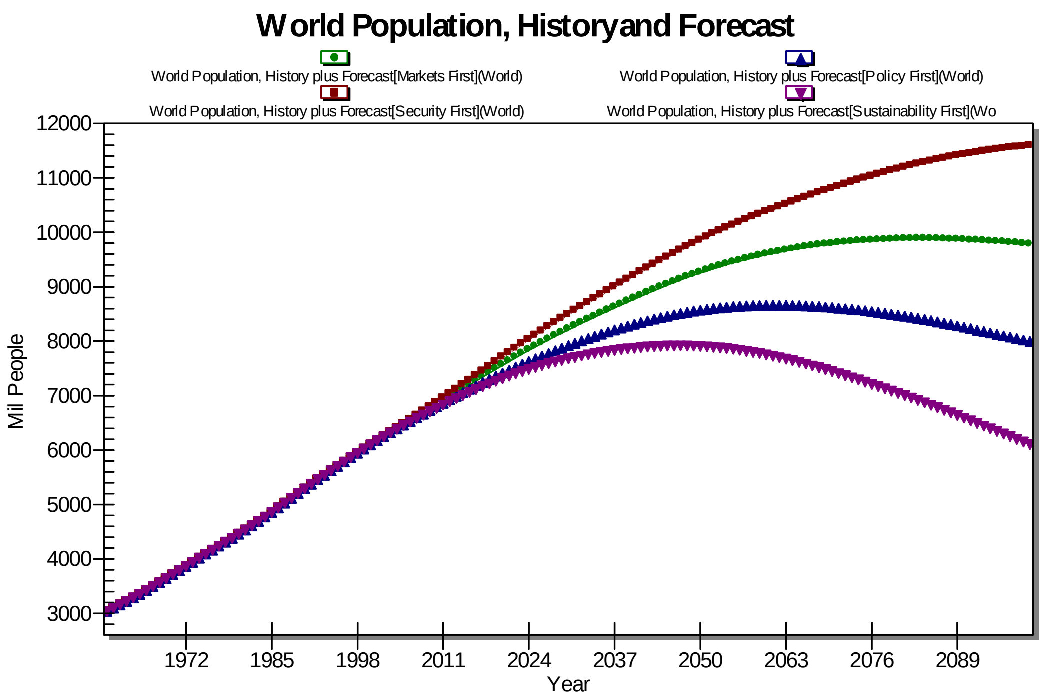
It was noted earlier that having the eyes of multiple domain experts on interventions and their results is critically important in assessing a model. The public availability of IFs and its considerable use in classrooms and broader analysis have provided regular feedback with respect to the base case and other forecasts. In the case of the UNEP GEO-4 project, however, a formal process was created involving a team of modelers from major related global modeling projects around the world and seven regional teams, corresponding to the seven regions into which UNEP divides the world. All of these process participants were given three different rounds of forecasts from IFs, focusing on demographic and economic drivers of relevance to the broader project, but including a number of other key variables. They were also given access to the IFs web site for further experimentation with the model. The feedback from this 2-year long process with many meetings of regional and total teams has been invaluable in improving the structure and forecasts of IFs.

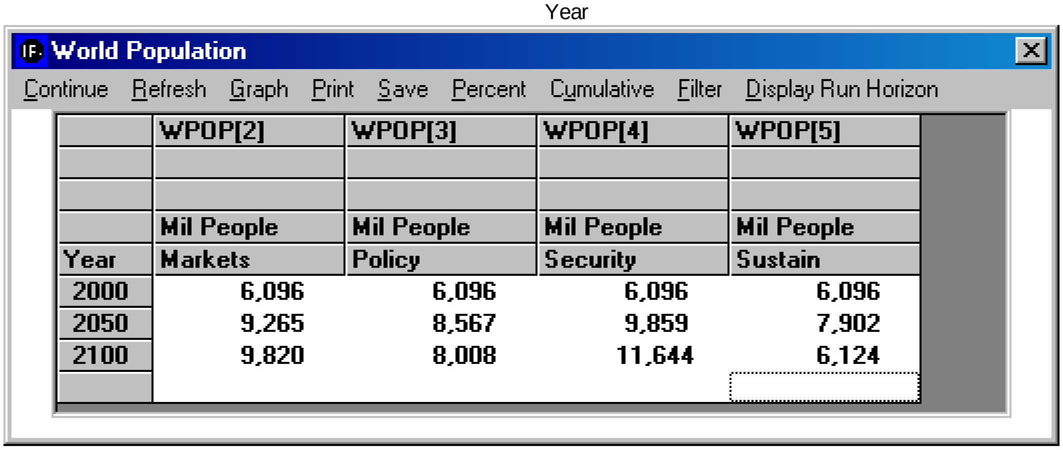
Both GEO-3 and GEO-4 have been built around four scenarios: Security First, Markets First, Policy First, and Sustainability First. These have roots in the scenarios of the Global Scenario Group (Raskin, Paul, et al. 2002). Their specific implementation in IFs involved the interventions in the table below.

UNEP GEO-4 Intervention Summary
IFs Model Inputs for GEO Scenarios

Intervention Category	Sub-Category	Security First	Markets First	Policy First	Sustainability First
Economic	Economic Freedom	10% Decrease	20% Increase		
	Trade Liberalization	Increase to 20% Traded Costs	Decrease to 10% Traded Costs		
	Productivity	0.5% Decrease Globally, 2% China, 1% South Asia	0.2% Increase Globally plus 0.25% Increase World (ex. US/Sub-Saharan)		
	Foreign Direct Investment	40% Decrease	50% Increase		
	Foreign Aid			Increase 0.2% to 0.4% from OECD	Increase 0.2% to 0.4% from OECD
	Research and Development			10% increase OECD 20% non-OECD in 20yrs	10% increase OECD 25% non-OECD in 20yrs
	Electronic Connectivity			20% in OECD 50% non-OECD in 20yrs	50% increase non-OECD
Political	Military Spending	20% Increase			
	Political Freedom	10% Decrease	10% Increase		
	Global Migration	25% Decrease	30% Increase		
Energy	Production of Natural Gas		Increase by factor of 1.5 to 2020		
	Discovery of Oil/Gas		50% Increase		
	Carbon Taxes			\$200/ton in 10yrs OECD \$50/ton in non-OECD in 15yrs	\$200/ton in 10yrs OECD \$50/ton in non-OECD in 15yrs
	Renewable Energy	Slowdown of Annual Reductions in Cost by 0.25%.		Doubling of Cost Reduction in 10 yrs.	Doubling of Cost Reduction in 10 yrs.
	Energy Demand			20% Reduction over 50 years	50% Reduction over 50 years
Health	Mortality Rates	10% Increase			
	Fertility Rates	20% Increase in 20 yrs		20% Reduction in non-OECD over 20 yrs	20% Reduction in non-OECD over 20 yrs
	Health Spending			10% increase OECD 20% non-OECD in 20yrs	10% increase OECD 25% non-OECD in 20yrs
Ed	Education Spending			10% in 20 yrs in OECD 20% in 20 yrs non-OECD	10% in 20 yrs in OECD 25% in 20 yrs non-OECD
Ag	Yield			Increase 20% over 10 years	Increase 20% over 10 years
Cultural					OECD Reduction of 40% of working life over 50yrs and 60% over 100
					Productivity Rates Decrease 0.5% in 20yrs
					Non-OECD fertility decrease of 40% over 50yrs
					Fertility Rate Reduction of 1.8 to 1.6

The range of futures created by these scenarios is quite great. Hughes (June 2005) compared the outcomes below with those of other forecasting projects. For instance, the forecasts of world population and GDP totals and growth rates were compared with scenarios from the United Nations, the International Institute of Applied Systems Analysis, analyses of the Global Scenario Group, the third Global Environment Outlook, and the Millennium Ecosystem Assessment.




World Population

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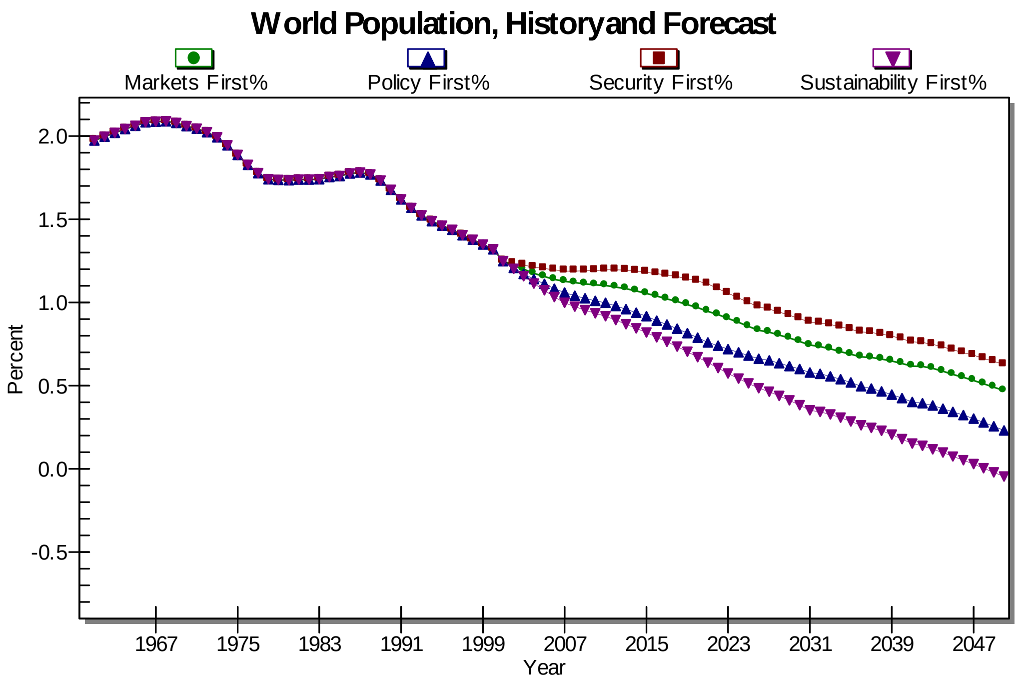
	WPOP[2]	WPOP[3]	WPOP[4]	WPOP[5]
	Mil People	Mil People	Mil People	Mil People
Year	Markets	Policy	Security	Sustain
2000	6,096	6,096	6,096	6,096
2050	9,265	8,567	9,859	7,902
2100	9,820	8,008	11,644	6,124



World Population Growth Rate

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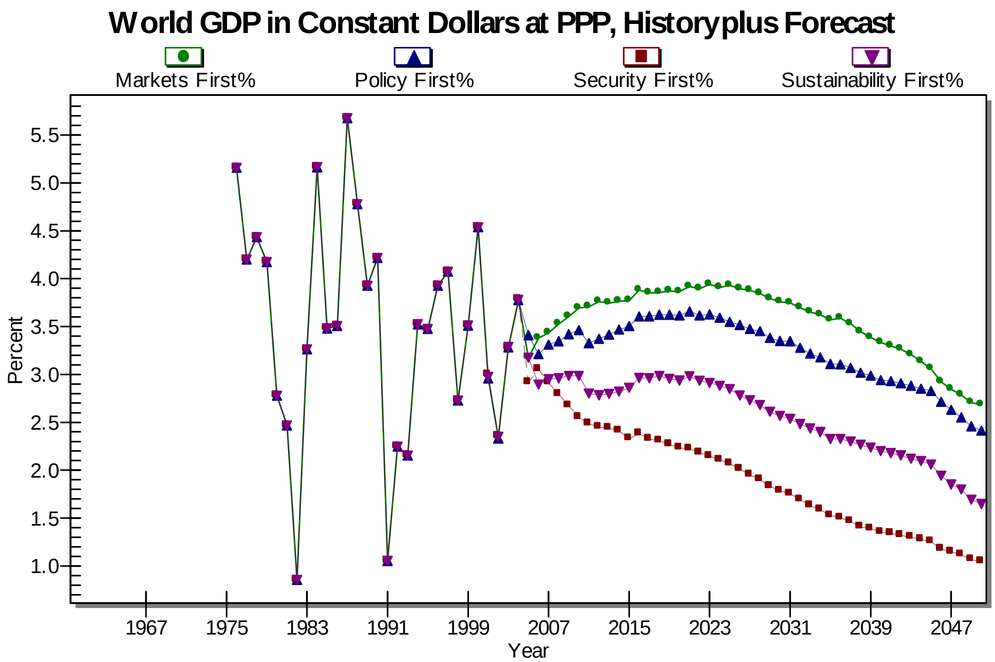
	WPOPR[2]	WPOPR[3]	WPOPR[4]	WPOPR[5]
	Percent	Percent	Percent	Percent
Year	Markets	Policy	Security	Sustain
2000	1.2278	1.2278	1.2278	1.2278
2050	.4356	.1906	.5901	-.0928



World GDP in Constant Dollars at Market

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	WGDP[2]	WGDP[3]	WGDP[4]	WGDP[5]
	Billion $	Billion $	Billion $	Billion $
Year	Markets	Policy	Security	Sustain
2000	34,281	34,281	34,281	34,281
2050	201,768	176,154	90,112	126,403
2100	690,384	560,648	161,761	280,901

World GDP in Constant Dollars at PPP

Continue Refresh Graph Print Save Whole Cumulative Filter Display Run Horizon

	GDPP[2]	GDPP[3]	GDPP[4]	GDPP[5]
	World	World	World	World
	% Change	% Change	% Change	% Change
Year	Markets	Policy	Security	Sustain
2000	.00	.00	.00	.00
2050	3.509	3.225	2.008	2.602

6.4 HDR plus 50: Poverty Analysis

The final project to be discussed here is one that is in an early stage at the time of this writing. The current work is to be the first of several volumes on improving the global human condition, consciously looking for inspiration to the United Nations Development Programme's series of *Human Development Reports*. The first volume will look in particular at the prospects for lowering rates of global poverty, as called for in the first and fundamentally the most basic of the Millennium Development Goals, but looking out to the middle of the century rather than only to 2015 (whether the poverty reduction goal is met by 2015 or not is all but in the pipeline). For the working document of this project see Hughes and Irfan (December 2005).

The three tables below show a set of domestic and international interventions, respectively, that are drawn from action plans such as those of Jeffrey Sachs and the UN Millennium Project (2005). They look at the implications for the numbers and percentages of individuals living in absolute poverty (less than one dollar per day) with each of the interventions alone and then in combinations. The text of the working document discusses and evaluates the results. Again, there will be a larger process with many eyes on the reasonableness of these results.

Log-Normal		Absolute Poverty (Millions)				
DOMESTIC	World	Non-OECD	SS Africa	World	Non-OECD	SS Africa
	2015	2015	2015	2050	2050	2050
Base Case	785	778	299	434	433	364
High Education	780	773	298	416	415	353
High Health Exp	783	776	299	417	416	353
High Econ Free	782	775	299	419	418	355
High Govt Effect	775	768	298	401	400	344
Low Corruption	778	771	298	394	393	340
High Infrastructure	781	775	299	413	412	357
High Renewable	785	778	298	437	436	372
High R&D	784	777	291	430	429	362
Low Protection	787	780	301	421	420	355
High Fem Labor	785	778	299	431	430	362
High Investment	791	784	299	406	405	336
High Transfers	753	746	288	404	403	345
All Domestic	724	717	286	241	240	216

Log-Normal		Absolute Poverty (Percent)				
	World	Non-OECD	SS Africa	World	Non-OECD	SS Africa
	2015	2015	2015	2050	2050	2050
Base Case	11.0	13.2	35.3	4.9	5.7	23.7
High Education	11.0	13.1	35.2	4.7	5.5	23.2
High Health Exp	11.0	13.1	35.2	4.6	5.4	22.8
High Econ Free	11.0	13.2	35.3	4.7	6.0	23.2
High Govt Effect	10.9	13.0	35.2	4.5	5.2	22.5
Low Corruption	10.9	13.1	35.2	4.4	5.1	22.2
High Infrastructure	11.0	13.2	35.4	4.6	5.4	23.2
High Renewable	11.0	13.2	35.3	4.9	5.7	24.3
High R&D	11.0	13.2	35.3	4.8	5.6	23.6
Low Protection	11.1	13.2	35.6	4.7	5.5	23.1
High Fem Labor	11.0	13.2	35.3	4.8	5.6	23.6
High Investment	11.1	13.3	35.4	4.6	5.3	22.0
High Transfers	10.6	12.7	34.0	4.5	5.3	22.4
All Domestic	10.2	12.2	33.8	2.6	3.1	14.2

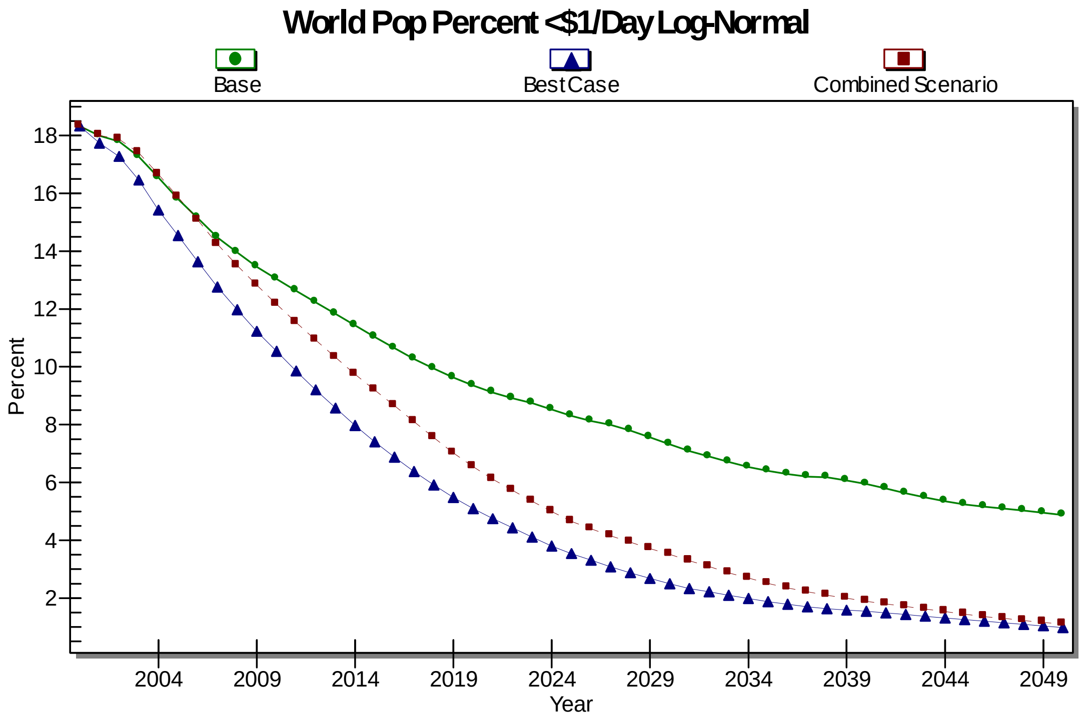
Log-Normal		Absolute Poverty (Millions)				
INTERNATIONAL	**World 2015**	**Non-OECD 2015**	**SS Africa 2015**	**World 2050**	**Non-OECD 2050**	**SS Africa 2050**
Base Case	785	778	299	434	433	364
High Trade	784	777	300	421	420	353
Export Promotion	785	778	299	431	430	362
High FDI	791	785	301	422	421	354
High Portfolio	785	778	299	434	433	364
High Remittances	781	774	298	415	414	348
High Foreign Aid	753	746	275	310	309	250
High IFI Flows	785	778	299	416	415	346
High Technology	777	770	297	398	396	339
All International	744	738	277	232	231	190

Log-Normal		Absolute Poverty (Percent)				
	World 2015	**Non-OECD 2015**	**SS Africa 2015**	**World 2050**	**Non-OECD 2050**	**SS Africa 2050**
Base Case	11.0	13.2	35.3	4.9	5.7	23.7
High Trade	11.0	13.2	35.4	4.7	5.5	23.0
Export Promotion	11.0	13.2	35.4	4.8	5.6	23.6
High FDI	11.1	13.3	35.6	4.7	5.5	23.2
High Portfolio	11.0	13.2	35.3	4.9	5.7	23.7
High Remittances	11.0	13.2	35.3	4.7	5.5	22.7
High Foreign Aid	10.6	12.7	32.2	3.5	4.1	16.3
High IFI Flows	11.0	13.2	35.3	4.7	5.4	22.5
High Technology	10.9	13.1	35.1	4.5	5.2	22.2
All International	10.5	12.5	32.5	2.6	3.0	12.6

Log-Normal		Absolute Poverty (Millions)				
PACKAGES	**World 2015**	**Non-OECD 2015**	**SS Africa 2015**	**World 2050**	**Non-OECD 2050**	**SS Africa 2050**
Base Case	785	778	299	434	433	364
Population	745	739	282	242	241	193
All Domestic	724	717	286	241	240	216
All International	744	738	277	232	231	190
Combined	644	637	247	88	87	77

Log-Normal		Absolute Poverty (Percent)				
	World 2015	**Non-OECD 2015**	**SS Africa 2015**	**World 2050**	**Non-OECD 2050**	**SS Africa 2050**
Base Case	11.0	13.2	35.3	4.9	5.7	23.7
Population	10.7	12.9	34.6	3.1	3.7	17.8
All Domestic	10.2	12.2	33.8	2.6	3.1	14.2
All International	10.5	12.5	32.5	2.6	3.0	12.6
Combined	9.2	9.2	30.1	1.1	1.3	7.0

The figure below looks at the prospective unfolding of absolute poverty rates in the base case, a combined scenario of interventions, and a best case scenario.



The reader and other analysts will need to help judge the reasonableness of the tables and graphs above. Comparisons should be made with the dynamic understandings that policy analysts and substantive experts have. This kind of dynamic, experimental evaluation of a model is an on-going, effectively never-ending process.

7. Conclusions

Assessing credibility of forecasts and forecasting instruments is not a simple process. The fact that forecasts of complex human systems are essentially always wrong — they are to help us think about the future, not to tell us what it will be — creates a somewhat difficult starting point.

It has been argued here that validity is an impossible standard, but that credibility, as something that accrues over time and with experience, is a standard that can be meaningfully considered. Credibility must be assessed relative to the purposes of a modeling project and its forecasts. In the case of IFs, the central purpose is to serve as a thinking tool for exploring long-term, global futures across multiple, interacting issue areas.

The case has been made here that several elements contribute to the accrual of credibility. One is the conceptual, theoretical, and empirical structure of a model (structural validity), as described in publications and papers. A second is the relationship between historical forecasts and empirical patterns, taking carefully into account the kinds of calibrations that are done to help a model better capture historical processes. A third is the character of a model's base case or reference forecast, one without additional interventions. And the fourth and final is the nature of the model's response to a wide range of interventions, singly and in combination. The last three of these are all aspects of behavioral validity.

It is hoped that this paper helps establish the basic credibility of forecasting with International Futures (IFs). Suggestions for improvement are always welcome.

Bibliography

Allen, Nicholas A., Clifford A. Shaffer, and Layne T. Watson. 2005. "Building Modeling Tools that Support Verification, Validation, and Testing for the Domain Expert," Proceedings of the 2005 Winter Simulation Conference, M.E. Kuhl, N.M. Steiger, F.B. Armstrong, and J.A. Jones, eds. Available at http://www.informs-cs.org/wsc05papers/045.pdf [January 2, 2006].

Arthur, James D. and Richard E. Nance. 1997. "Verification, Validation, and Accreditation: Disciplines in Dialogue or Can we Learn from The Experience of Others?" Proceedings of the 1997 Winter Simulation Conference, ed. S. Andradóttir, K.J. Healy, D.H. Withers, and B.L. Nelson. Available at http://www.informs-sim.org/wsc97papers/0489.PDF [January 2, 2006]

Bankes, Steven C. and James Gillogly. 1994. *Validation of Exploratory Modeling*. Santa Monica, CA: RAND. RP-345. Web page extract at http://www.evolvinglogic.com/news/el_chance.html [January 2, 2006]

Barlas, Y. (1996) Formal Aspects of Model Validity and Validation in System Dynamics, *System Dynamics Review* , Fall, 12(3) :183-210.

Bremer, Stuart A., ed. 1987. *The GLOBUS Model: Computer Simulation of World-wide Political and Economic Developments.* Boulder, CO: Westview Press.

Chadwick, Richard W. 2006. "Korea 2020, National Security Futures, Development, Democracy, and Choices: Building a Korea Peace Structure," University of Hawaii, unpublished paper originally prepared for the World International Studies Association conference in Istanbul, Turkey, August 2005.

Cook, David A. and James M. Skinner. 2005. "How to Perform Credible Verification, Validation, and Accreditation for Modeling and Simulation," Systems and Software Technology Conference, in CrossTalk, The Journal of Defense Software Engineering (May): 20-23. Available at http://www.stsc.hill.af.mil/crosstalk/2005/05/0505Cook.pdf [January 2, 2006]

Hillebrand, Evan. 2006. "The Global Distribution of Income in 2050," University of Kentucky, unpublished paper originally prepared for the World International Studies Association conference in Istanbul, Turkey, August 2005.

Hillston, Jane. 2003 (September 19). "Model Validation and Verification," Lecture Notes 14 in class on Modelling and Simulation, University of Edinburgh, School of Informatics, available at http://www.inf.ed.ac.uk/teaching/courses/ms/ [January 2, 2006].

Hodges, James S. and James A. Dewar. 1992. "Is It You or Your Model Talking? A Framework for Model Validation." Santa Monica, CA: RAND R-4114-AF/A/OSD.

Hossain, Anwar with Barry B. Hughes. 2004 (July). The Database of International Futures. Unpublished IFs working paper on the IFs website.

Hughes, Barry B. 1980. *World Modeling*. Lexington, Mass: Lexington Books.

Hughes, Barry B. 1985a. *World Futures: A Critical Analysis of Alternatives*. Baltimore: Johns Hopkins University Press.

Hughes, Barry B. 1985b. "World Models: The Bases of Difference,*" International Studies Quarterly* 29, 77-101.

Hughes, Barry B. 1986. "The First Two Oil Shocks: Policy Response and Effectiveness," *Policy Studies Review,* vol. 5, no. 4 (May), pp. 722-741. Selected by the Policy Studies Organization for the Fourth Annual Jeffrey Pressman Award as the outstanding article published in *Policy Studies Review* during 1986.

Hughes, Barry B. 1987. "Domestic Economic Processes," in Stuart A. Bremer, ed., *The Globus Model: Computer Simulation of Worldwide Political Economic Development* (Frankfurt and Boulder: Campus and Westview), pp. 39-158.

Hughes, Barry B. 1988. "International Futures: History and Status," *Social Science Microcomputer Review* 6, 43-48.

Hughes, Barry B. 1993, 1996, 1999. *International Futures: Choices in the Face of Uncertainty*, 1st, 2nd, and 3rd editions. Boulder, Colorado: Westview Press.

Hughes, Barry B. 1997. "Rough Road Ahead: Global Transformations in the 21st century," *Futures Research Quarterly* 13, No. 2 (Summer): 83-107.

Hughes, Barry B. 1999. "The International Futures (IFs) Modeling Project," *Simulation and Gaming* 30, No. 3 (September): 304-326.

Hughes, Barry B. 2001a. "Choices in the Face of Uncertainty: The International Futures (IFs) Model, *Futures* 33 (2001): 55-62.

Hughes, Barry B. 2001b. "Global Social Transformation: The Sweet Spot, the Steady Slog, and the Systemic Shift," *Economic Development and Cultural Change* 49, No. 2 (January): 423-458

Hughes, Barry B. 2002. "International Futures (IFs) Model," *UNESCO Enclyclopedia of Life Support Systems (EOLSS)*, Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UN, [http://www.eolss.net].

Hughes, Barry B. and Anwar Hossain. 2003 (September). Long-Term Socio-Economic Modeling: With Universal, Globally-Integrated Social Accounting Matrics (SAMs) in a General Equilibrium Model Structure. Unpublished IFs working paper on the IFs website.

Hughes, Barry B. 2004. “Regimes and Social Transformation,” in Arild Underdal and Oran Young, *Regime Consequences: Methodological Challenges and Research Strategies*, Kluwer Academic Publishers.

Hughes, Barry B. 2004 (February). Forecasting the Human Development Index (HDI), Unpublished IFs working paper on the IFs website.

Hughes, Barry B. 2004 (March). The Base Case of International Futures (IFs): Comparison with Other Forecasts. Report of the IFs project for the National Intelligence Council and other use. University of Denver, unpublished manuscript.

Hughes, Barry B. with Anwar Hossain and Mohammod T. Irfan. 2004 (May). “The Structure of IFs,” Unpublished IFs working paper on the IFs website.

Hughes, Barry B. 2004 (July). “Scenario Analysis with International Futures (IFs), unpublished IFs working paper on the IFs website

Hughes, Barry B. 2004 (October). “2020 Project: IFs Scenario Implementation,” unpublished IFs working paper.

Hughes, Barry B. and Peter Johnston. 2005. “Sustainable Futures: Building Policy Options into A Scenario for Development in a Global Knowledge Society,” *Futures* 37: 813-831.

Hughes, Barry B. 2005 (March 1-5). Global Transitions Foreseen: Using International Futures (IFs) to Help Manage the Future, paper prepared for the 46th Annual Conference of the International Studies Association, Honolulu, Hawaii.

Hughes, Barry B. 2005 (May No. 1). Forecasting Productivity and Growth with International Futures (IFs), Part 1: The Productivity Formulation, Unpublished IFs Working Paper.

Hughes, Barry B. 2005 (May No. 2). Forecasting Productivity and Growth with International Futures (IFs), Part 2: Driving the Drivers and Indices, Unpublished IFs Working Paper.

Hughes, Barry B. 2005 (June). UNEP GEO-4 Driver Scenarios: Using IFs with Pardee, 3rd version, unpublished working paper for UNEP GEO-3 project in progress.

Hughes, Barry B. and Mohammod Irfan. 2005 (December). Forecasting Global Poverty Reduction: HDR Plus 50, unpublished IFs working paper as foundation for Pardee-sponsored project with RAND. Paper presented at the 47th Annual Conference of the International Studies Association, San Diego, California.

Hughes, Barry B. and Evan E. Hillebrand. 2006. *Exploring and Shaping International Futures.* Boulder, Co: Paradigm Publications.

Hughes, Barry B. 2006 (February). Introduction to IFs, 3rd revision, unpublished IFs working paper on the IFs website.

Hughes, Barry B. 2006 (April 6-8). Forecasting Globalization: The Use of International Futures (IFs), paper prepared for the research seminar on Globalization as Evolutionary Process: Modeling, Simulating, and Forecasting Change, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Hughes, Barry B. 2006 (May). The Data Preprocessor of International Futures, Unpublished IFs working paper.

Huntington, Samuel P. 1991. *The Third Wave: Democratization in the Late Twentieth Century*. Norman: University of Oklahoma Press.

Irfan, Mohammod T. 2005 (August). "Financing Universal Primary Education Under Structural Constraints," University of Denver, unpublished paper originally prepared for the World International Studies Association conference in Istanbul, Turkey.

Kant, Immanuel. 1795. *Perpetual Peace: A Philosophical Sketch.* Subsequently republished in several forms and volumes.

Lempert, Robert J., Steven W. Popper, and Steven C. Bankes. 2003. *Shaping the Next One Hundred Years: New Methods for Quantitative Long-Term Policy Analysis.* Santa Monica, CA: The RAND Pardee Center.

Macal, Charles M. 2005 (April 7-9). Model Verification and Validation, presentation at the Workshop on "Threat Anticipation: Social Science Methods and Models," The University of Chicago and Argonne National Laboratory, Chicago IL.

Maddison, Angus. 2001. *The World Economy: A Millennial Perspective*. Paris: Organization for Economic Cooperation and Development.

Meadows, Donella H., Dennis L. Meadows, Jorgen Randers, and William W. Behrens III. 1972. *The Limits to Growth* (New York: Signet).

Meadows, Donella, Dennis Meadows, and Jorgen Randers. 2004. *Limits to Growth: The 30-Year Update.* White River Junction, Vermont: Chelsea Green Publishing Company.

Millennium Project. 2005. *Investing in Development: A Practical Plan to Achieve the Millennium Development Goals*. London: Earthscan Publications Ltd.

Qudrat-Ullah, Hassan. 2005. "Structural Validation of System Dynamics and Agent-Based Simulation Models," Proceedings of the 19th European Conference on Modelling and Simulation. Riga, Latvia (June 1-4, 2005). ISBN 1-84233-112-4. Author at York University School of Administrative Studies, Toronto, Canada.

Available at http://www.econ.iastate.edu/tesfatsi/EmpValidSDACE.Hassan.pdf [January 2, 2006]

Raskin, Paul, et. Al. 2002. *Great Transition: The Promise and Lure of the Times Ahead.* Boston, MA: Stockholm Environment Institute. Available at http://www.tellus.org/seib/publications/Great_Transitions.pdf Accessed June 16, 2006.

Rawls, John. 1971. *A Theory of Justice*. Cambridge, MA: Harvard University Press.

Roy, Santanu and Pratap K.J. Mohapatra. 2003. "Methodological Problems in the Formulation and Validation of System Dynamics Models Incorporating Soft Variables," paper delivered at the 21st Systems Dynamics Conference New York (July 20-24). Available at http://www.systemdynamics.org/conf2003/proceed/PAPERS/920.pdf [January 2, 2006]

Sargent, Robert G. 1998. "Verification and Validation of Simulation Models," Proceedings of the 1998 Winter Simulation Conference, D.J. Medeiros, E.F. Watson, J.S. Carson, and M.S. Manivannan, eds.

Sargent, Robert G. 2000. "Verification, Validation, and Accreditation of Simulation Models," Proceedings of the 2000 Winter Simulation Conference, J.A. Joines, R.R. Barton, K. Kang, and P.A. Fishwick, eds. Available at http://www.informs-sim.org/wsc00papers/009.PDF [January 2, 2006]

Schwarz, Peter. 1991. *The Art of the Long View: Planning for the Future in an Uncertain World.* New York: Doubleday.

Schwarz, Peter. 2003. *Inevitable Surprises: Thinking Ahead in a Time of Turbulence.* New York: Gotham Books.

Sen, Amartya. 2000. *Development as Freedom*. New York: Anchor Books.

Senese, Paul. 2005. "Chinese Acquisition of the Spratley Archipeligo and its Implications for the Future," SUNY-Buffalo, unpublished paper originally prepared for the World International Studies Association conference in Istanbul, Turkey, August 2005.

United Nations. 1987. The World Commission on Environment and Development (Brundtland Commission), *Our Common Future*. Oxford: Oxford University Press.

United Nations Environment Program (UNEP). 2002. *Global Environment Outlook 3*. London: Earthscan Publications Ltd.

United States National Intelligence Council. 2004 (December). *Mapping the Global Future*. Washington, D.C.: USGPO.

Wack, Pierre. 1985a (September-October). "Scenarios: Uncharted Waters Ahead," *Harvard Business Review*, pp. 73-89.

Wack, Pierre. 1985b (November-December). "Scenarios: Shooting the Rapids," *Harvard Business Review*, pp. 139-150.