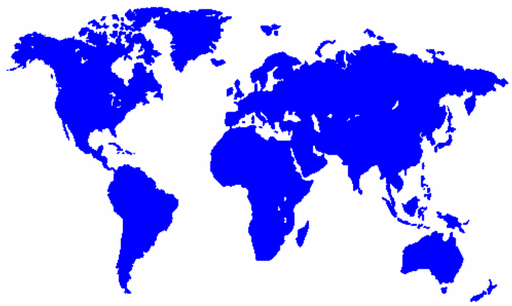

Forecasting Global Economic Growth with Endogenous Multifactor Productivity: The International Futures (IFs) Approach

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Abstract

A very wide range of policy-oriented economic forecasting requires attention to the impact of action and inaction on productivity and economic growth. Yet, relatively little longer-term economic forecasting endogenously links multiple policy-based variables to productivity.

The International Futures (IFs) modeling project has developed an approach to endogenizing productivity for forecasting purposes within an extensive system of models, building on a variety of advances in theoretical and empirical foundations. The approach combines attention to technological change in a systemic leader with a non-linear representation of convergence potential in other countries and additive shifts in productivity tied to a wide range of drivers in multiple categories. Other modules in the larger system of models endogenously determine most of the drivers in the productivity formulation, but model users can additionally manipulate them directly for what-if analysis.

In spite of many weaknesses in the approach, it produces forecasts for 182 countries or aggregations of them across a substantial historical period (1960-2000) and well into the century (with and without interventions related to the drivers) that are reasonably consistent with expectations and with other work. As a system, it is fundamentally unique in its ability to explore long-term national and global economic growth and its consequences across a wide range of alternative assumptions.

1. Introduction

A very wide range of country-based, regional and global policy analyses require forecasts of economic growth. In spite of our understanding that productivity growth can differ greatly across countries or time periods with similar savings rates and labor force growth, and notwithstanding our growing knowledge of the bases for such variation, much economic forecasting involves limited or no endogenous representation of productivity growth.

For very long-term forecasting, that omission may be largely appropriate. Analysis may only require economic forecasts as drivers of other variables such as energy demand or environmental impact of producers and consumers. For forecasts in the very long term, such as 100 or more years, exogenous specification of economic growth rates thus suffices, perhaps in combination with an effort to link back the variables driven, such as environmental damage from global warming, to the economic gains or losses they create, so as to explore the costs and benefits of avoidance or mitigating action. Such approaches generally characterize modeling and forecasting efforts including FUND (Tol 1999), MESSAGE-MACRO (Messner and Schrattenholzer 2000), and MERGE (Mann and Richels 2004).

Similarly, for quite short-term forecasting endogenous representation of productivity change may be unnecessary. At the extreme, comparative static analysis in the tradition of computable general equilibrium (CGE) models may be independent of time. And even many more dynamic CGE forecasts are relative short-term, over periods during which investments in human capital, changes in institutional quality, and increases or decreases in economic openness may be reasonably assumed not able to alter productivity and growth in any significant manner. Exogenous or no explicit assumptions of productivity change again can suffice. CGE models generally depend very heavily on the specification and calibration of the SAM structure in the base year, somewhat restricting their temporal dynamics.

There is, however, a considerable intermediate forecasting horizon and a large set of policy analyses for which representation of productivity growth endogenously can make a substantial analytical contribution. The 15-year time horizon of the Millennium Development Goals between their official announcement and their target dates (2000 and 2015, respectively) and the 25-year total horizon of those goals (1990-2015) clearly fit into that intermediate range. Over such periods, and even in somewhat shorter ones such as those of the Poverty Reduction Strategy Papers (PRSPs), the implications of differential governance quality and investments in human capital certainly will affect growth and the ability of countries or regions to meet goals for the reduction of poverty, the spread of primary and secondary education, and the reduction of mortality rates.

In fact, the obvious functioning of feedback loops connecting policy initiatives, objectives and economic growth call out for the approach of an integrated assessment model in which economic, demographic, and socio-political modules are integrated and productivity growth responds to demographic and socio-political change.

For the most part, however, such integrated structures have not characterized forecasting across this intermediate horizon. To a considerable degree, economic models stand alone. For instance, the CORE version of WorldScan (CPB 1999) and LINKAGE (van der Mensbrugghe 2005) are exclusively economic models. LINKAGE supports the poverty forecasts of the World Bank's annual *Global Economic Prospects*.

Many models used for analysis within this intermediate time horizon are dynamic computable general equilibrium models, made dynamic by the accumulation of capital stocks (with investment and depreciation flows), the exogenous representation of labor force growth and the exogenous representation of productivity growth. The exogenous representation of productivity is sometimes partially modified. For instance, in LINKAGE it is responsive to trade openness. WorldScan regions can differ in productivity growth as a result of explicit catching up or convergence of less economically developed countries (an approach used in much OECD forecasting). Very-long term models used for analysis of environmental change sometimes link the availability of energy to technological change.

The development of support systems for CGE modeling, such as GAMS (the General Algebraic Modeling System; see Lofgren, Harris and Robinson 2002) and the data bases of GTAP (the Global Trade and Analysis Project) and many country-SAM projects, have simplified the creation and enhanced the quality of CGE-models[1] and their temporal extensions (Lofgren, Lee Harris, Robinson 2002). Increasingly, many models attempt to combine CGE formulations with macro economic representations to enhance treatment of dynamics and with meso or macro elements to allow assessment of economic changes on representative households or a full sample of household surveys (Bourguignon, Pereira da Silva and Stern 2002) or with respect to specialized issues.[2] The LINKAGE connection to the GIDD (Global Income Distribution Dynamics) tool is an example (Bussolo, De Hoyos, Medvedev, and van der Mensbrugghe 2007).

For instance, at the country or regional level, the MAMS model (<u>MA</u>quette for <u>M</u>DG <u>S</u>imulation) is described as an extended dynamic-recursive CGE model. Applied by 2007 to 26 Latin American and African countries, its extension includes a module for forecasting the production of social sectors such as education in relationship to the MDGs. Total factor productivity (TFP) in MAMS is partly endogenous, depending with elasticities on economic openness and capital accumulation, and otherwise exogenous (Lofgren and Diaz-Bonilla 2006: 12; see also Vos, Sánchez, and Inoue 2007; Lofgren, Diaz-Bonilla, and Timmer 2007; Lofgren 2004).[3]

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[1] CPB (1999: 2-3) describes WorldScan as an Applied General Equilibrium (AGE) model.

[2] The longer the forecast horizon, the greater the relative weight of economic growth becomes relative to income distribution in poverty reduction. And we have little ability to forecast change in income distribution in the longer-term. Hence such macro-micro analysis tends to focus on the relatively nearer term.

[3] Bourguignon (2004) described a framework for monitoring the MDGs, based on MAMS, which conceptually closes the loops back to the economy. UNDP-RBAS, UN-DESA/DPAD, and World Bank (2006) elaborates some recent development plans with MAMS.

Another example is IMMPA (Integrated Macroeconomic Model for Poverty Analysis), described as a dynamic CGE model or a dynamic financial CGE (Agénor, Izquierdo and Fofack 2003; see also Houenvino, Adjovi and Ekue 2005; Yeldan 2005). Special features include detailed attention to labor markets and extensive attention to the financial system. Production does not include specification of productivity change.

In general, as useful as the current generation of CGE models is, the forecasting systems available for the time horizon over which changes in the rate of productivity growth could be significant (1) tend endogenously to represent somewhat limited potential drivers of change in productivity and (2) tend not to feed back some key computed variables (such as human capital development) to an endogenous representation of productivity.

This paper will explore how additional steps might be taken. It will first look to the literatures, theoretical and empirical, on productivity. It will then examine the approach taken by the International Futures (IFs) modeling system, a multi-country, multi-issue and long-term simulation, to extending the representation of endogenous drivers and to closing of broader loops within the model.

The goal of such effort is, again, to enhance policy analysis, which requires forecasts with and without intervention and which benefits from as full an endogenization of the central dynamics of the forecasting system as possible. Productivity growth, responsive to so many of the consequences of economic growth and decisions concerning its character, is such a central dynamic.

2. Theoretical and Empirical Background

Many analysts (among them Barro and Sali-i-Martin 1999; Ruttan 1998; Jones 2002) have related well the evolution of economic growth theory and its interplay with the more empirically- and policy-centered analysis of development economics.[4] That continuing evolution has helped us increasingly understand both the importance and character of what analysts variously call the Solow residual, technological change, and total or multifactor productivity (TFP or MPF), the contribution to growth that increased capital stock and worker-hours cannot explain. This paper and project uses the MPF label.

Classical economists (including Smith, Ricardo, Malthus, Ramsey, and Schumpeter) provided foundational ingredients for the story, including the equilibrating interplay of demand and supply. They identified the importance of capital accumulation (physical and human) and explored the likelihood of decreasing returns to capital and cessation of growth per capita.

Neoclassical economists elaborated on those foundations, elaborating the optimizing of households and firms across activities and over time (e.g. Ramsey 1928; Modigliani and Brumberg 1955; Friedman 1957), developing production functions (e.g. Harrod 1942; Domar 1946; Solow 1956; Swan 1956) including the Cobb-Douglas function with constant returns to scale and smooth substitution between capital and labor, and formalizing the general equilibrium model. They also hypothesized and empirically explored (conditional) convergence of economies over time, linked in part to decreasing returns within the wealthier ones. Their formalizations included that of technological change as an element in the Cobb-Douglas equation. That term helped represent the continuation of economic growth over a very long period (as well as offering hope of its continuation well into the future) and the phenomenon of economic divergence. It also, however, moved much of the explanation for growth into an exogenous term, a black box with respect to the understanding and therefore also forecasting of growth.

Efforts to open up the black box, ultimately labeled new economic growth theory or endogenous growth theory, began early with attention to technological innovation and diffusion, for instance by Arrow (1962) with a complex but very restricted model around learning-by-doing in the capital goods industry. For a variety of reasons, including weaknesses in empirical bases, theoretical proclivities such as perfect competition and rational expectations that favor rapid or instantaneous adjustment processes in models built upon them, and the need of policy to focus on the economic shocks of the 1970s and their aftermath, further exploration of productivity drivers slowed substantially for many years.

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[4] The research of George Horton made important contributions to the discussion of this section.

In the late 1980s, work accelerated again with efforts to tie the micro-economic foundations of research and development (R&D) efforts by agents, producing the externality-rich, non-rivalrous, partially excludable good of knowledge in imperfectly competitive markets, to broader technological advance in societies and globally (Romer 1990 and 1994; Aghion and Howitt 1992; Grossman and Helpman 1991). Lucas (1988) similarly explored the externalities associated with worker decisions to trade off current consumption for increased human capital. The theories and formal models open up the exploration of a wide range of drivers of successful R&D initiatives, including a range of government institutions and policies and connections to broader trade and financial markets.

In spite of the advances in the new growth theory, the relationship of it and development economics, including forecasting models (as opposed to formal models and historic analysis) is somewhat cool. Ruttan (1998) identified several areas of interest to development economics that growth economics largely ignores. One is structural socio-economic transformation, a la Clark (1940) and Chenery, Robinson and Syrquin (1986); Syrquin (1988); see also Syrquin (1998) on the inattention to it by growth economics. Ruttan's list also includes the demographic transition (potentially building on development-based analysis of fertility decisions), natural resource constraints, income distribution, and institutional change.

Empirical work has the potential for being a significant bridge between growth theory and development economics. Clearly, even though everyone understands that replacement and accumulation of capital are fundamental carriers for technology's impact, the estimate by Solow (1957: 320) that technical change accounted for 87.5 percent of growth in economic output per worker-hour in the US between 1909-49 focused the minds of everyone interested in growth on the Solow residual.[5] From growth accounting estimates in four panels of countries Barro and Sala-i-Martin (1999: 380-381) reported unweighted average estimates of TFP that are considerably lower, but still impressive: 40.7 percent for seven OECD countries, 1947-1973 (33.6 percent for the US); 34.8 percent for the G-7 countries, 1960-1990 (13.2 percent for the US); 24.3 percent for seven Latin American countries, 1940-1980; 14.2 percent for four East Asian countries, 1966-1990. Even though it is generally understood that the productivity share of growth is lower in less developed countries than in the OECD, it is clearly sufficiently high and variable to be an important factor in growth forecasting.

Empirical analysis of productivity and growth has benefited greatly from a number of data developments. One is the expansion with purchasing power parity by Gilbert and Kravis (1954) and Kravis, Kenessey, Heston, and Summers (1975) of the already

[5] Not the first to produce such an estimate, Solow (1957: 317) credited Fabricant (1954) with having estimated 90 percent for the 1871-1951 period.

impressive system of national accounts that Kuznets and Stone pioneered. That laid groundwork for extensive cross-sectional analysis. Similarly, Angus Maddison (1995, 2001) has greatly extended economic series historically for longitudinal analysis. The annual World Bank's *World Development Indicators* continues to help organize and extend a database that greatly helps explore the drivers of productivity.

Looking to more integrated or structural representations, Leontief's (1941) input-output matrices laid one of the foundations along with national accounts for social accounting matrices (again influenced by Stone 1947), making possible some of the early work on general equilibrium (GE) models by Scarf (1967) and his students Shoven and Whalley (1972). Even though consistent SAMs across many countries remain elusive, impressive development of IO matrices and SAMs have continued with initiatives such as Thomas Hertel's Global Trade and Analysis Project (GTAP) and extensive application-specific work building on Pyatt and Thorbecke (1976) and Pyatt and Round (1985).

Many have built on these empirical foundations, keeping eyes on growth theory and development literatures, to help us understand the deeper variables that drive technological change, multifactor productivity, or growth more generally. The empirical results are too extensive to report here (Hughes 2005 reviewed and compared some for the IFs project).

Mankiw, Romer and Weil (1992) provided empirical analysis focusing sharply on the strengths and weaknesses of the Solow growth model. Two Barro books (Barro 1997/99 and Barro and Sala-i-Martin 1995/1999) are among the classics of extensive, multifactor productivity studies. The first one examined a very extensive range of possible productivity drivers across 97 countries using a panel design over two decades, 1965-75 and 1975-85. The second examined "roughly 100 countries" from 1960 to 1990, using three periods (1965-75, 1975-85, 1985-1990) and initial condition specification in 1960. The panel design allowed some analysis of possible causal sequence.[6] Papers by Bosworth and Collins (2003) and Chen and Dahlman (2004) are two other widely known and extensive analyses.[7]

[6] Both volumes used a conditional convergence model. Conditional convergence theory generally posits that it is easier for countries (or companies) to catch up technologically than to innovate, but that doing so does require considerable effort and positioning. For instance Barro and Sala-i-Martin (1999: 269) cited Mansfield, Schwartz, and Wagner (1981: 908-909) as having found "that the cost of imitation averaged 65% of the cost of innovation" with a range across 48 products from 40% to 90%. Barro and Sala-i-Martin suggest that convergence occurs at 3.0% per year (1999: 431) if other variables are held constant (positioned so as to contribute to the conditional convergence).

[7] See also Jamison, Lau and Wang (2004 revision) and Baldacci, Clements, Gupta, and Cui (2004). Look also to OECD volumes (2003, 2004).

Durlauf, Johnson, and Temple (2005) did a masterful job of reviewing and analyzing "Growth Econometrics" for the *Handbook of Economic Growth*. They framed their presentation with considerable skepticism:

> The empirical study of economic growth occupies a position that is notably uneasy. Understanding the wealth of nations is one of the oldest and most important research agendas in the entire discipline. At the same time, it is also one of the areas in which genuine progress seems hardest to achieve. The contributions of individual papers can often appear slender. Even when the study of growth is viewed in terms of a collective endeavor, the various papers cannot easily be distilled into a consensus that would meet standards of evidence routinely applied in other fields of economics. (p. 558)

They viewed the enterprise as too important not to proceed. And they concluded (2005: 651) that, while still in its infancy, there has been progress that "gives reason for continued optimism." Their Appendix B summarized a remarkable range of literature.

Figure 1 suggests, however, that the empirical "bridge" between growth and development theory with respect to the understanding of productivity might more accurately be called a "zone of interaction". Growth theory continues to strengthen micro-economic foundations and to sally into empirical analysis, especially around institutions, human capital, and international flows. Empirical analysis from development economics continues to explore a wide range of productivity drivers individually and in combination, generally meshing with the interests of growth theory, but with greater disaggregation and extent.

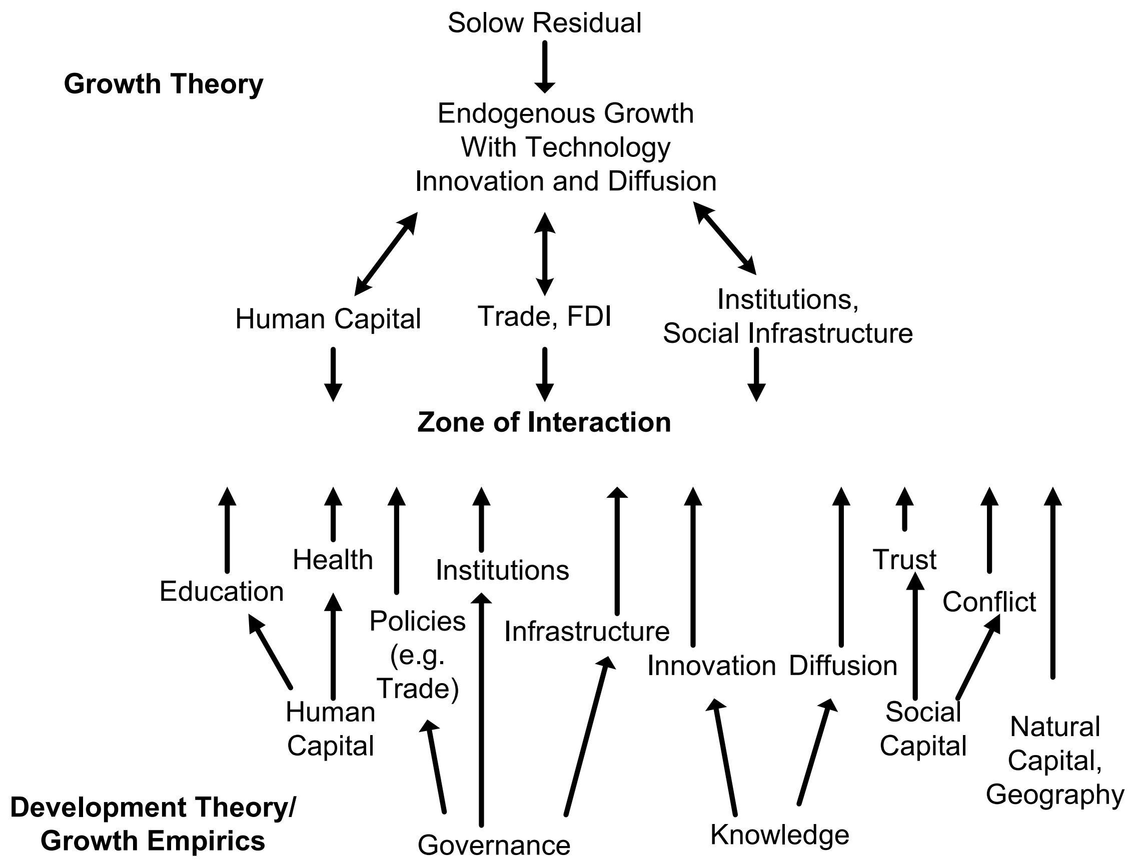

Figure 1. Thinking About Productivity

In summary, theoretical and empirical foundations for enhancing the treatment of productivity in forecasting models have become stronger and demonstrate increasing interaction. The next section turns to an effort to build on them.

3. Endogenizing Productivity in IFs

To recap: (1) much country-based and global policy analysis requires economic forecasting under different scenarios (with and without interventions); (2) economic forecasting over the extensive time horizon across which productivity growth is uncertain and important tends neither to represent explicitly the drivers of productivity nor to feed back the consequences of economic growth to such drivers, in spite of the acknowledged importance of productivity change; (3) the theoretical and empirical base for more extensive endogenous representation of productivity change has strengthened. It therefore should be possible to enhance economic models and their analysis with respect to the dynamic representation of productivity.

This section briefly introduces the International Futures (IFs) modeling system and discusses its approach to modeling productivity. The next section considers examples of the system's use.

3.1 International Futures (IFs): An Overview

International Futures (IFs) is a country-based, long-term global modeling system. The system contains an extensive database of variables since 1960 for 182 countries. Forecasts for countries or regional aggregations extend into or through the century as desired.

IFs is an integrated assessment model or system of models in which the economic module is extensively linked to other modules (see Figure 2). The economic module itself is a dynamic, recursive general equilibrium model. The production side represents six sectors with Cobb-Douglas production functions and input output matrices that change with economic development. The consumption side represents household consumption within a linear expenditure system using Engel elasticities and represents government consumption in a separate socio-political module with extended revenue and expenditure dynamics. A social accounting matrix wraps the goods and service markets, representing flows among households (only skilled and unskilled labor), governments and firms; it also represents key stocks such as government and international balances. Trade uses a pool rather than bilateral representation. Sector-specific prices change in response to dynamic inventory stocks and equilibrate production and consumption over time rather than instantaneously. Similarly, country-specific changes in exchange rates respond to the accumulation of current account balances in debt or asset stocks and equilibrate international flows over time.

The demographic module is cohort-component in structure with age categories to 100 plus; the economic module influences endogenous computations of fertility and mortality. The education module forecasts student flows through primary, secondary and tertiary levels; linkage to fertility patterns influence economic productivity (to be discussed below), while economic variables influence government budgets and thus education supply. The partial equilibrium module for energy represents seven different types on the supply side and the partial equilibrium module for agriculture represents crop, meat and fish production and consumption. The economic module heavily influences demand and supply in both modules. In turn, in the default instance physical values from both partial equilibrium models, converted to value terms, override values in the respective sectors of the economic module. Hughes and Hillebrand (2006) and Hughes, Hossain, and Irfan (2004) provide extensive model documentation; the Help system of IFs, available with it at www.ifs.du.edu, provides complete flow diagrams, equations, and model code.

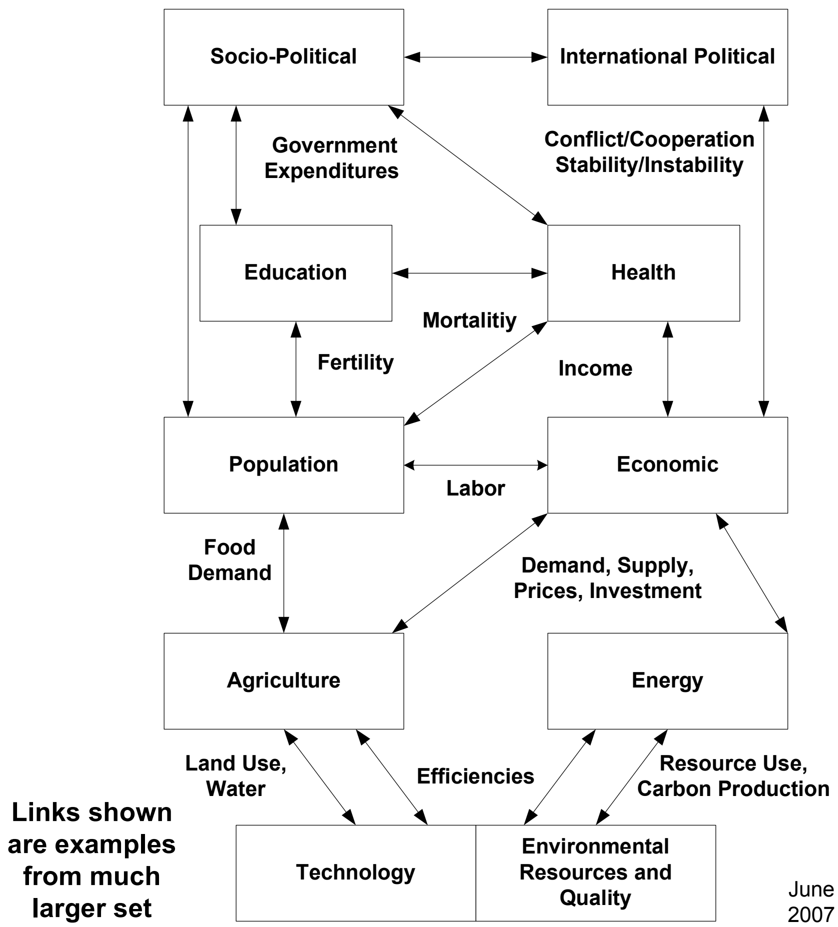

Figure 2. Modules of the International Futures (IFs) System

3.2 Production and Productivity in IFs: Basic Structure

Most economic forecasting and most growth empirics build on the Cobb-Douglas function. More extensive growth empirics decomposes the technology, MFP, or TFP term into multiple elements and estimates their absolute and relative contributions. For example, Chen and Dahlman (2004) ultimately broke the drivers of TFP into four categories. In their words (2004:8):

> In essence, the aggregate production function has the specification of
>
> $$Y = A(g,e,r,i).F(K,L)$$
>
> where
>
> g represents institutional and economic regime of the economy
> e represents education and training
> r represents country's level of domestic innovation (includes both creating new technology and technology adaptation)
> i represents country's information and communication infrastructure

Chen and Dahlman examined a range of indicators in each of the four categories of drivers, often combining them in the analysis. IFs similarly uses the Cobb-Douglas formulation and forecasts MFP endogenously from a range of categories and elements in them.[8]

Among the important issues to consider in the structuring of economic forecasting with endogenous productivity are the following:

- What should be the categories and the elements within them? Although forecasts for drivers of productivity can, of course, be specified exogenously, it is desirable to be able to endogenously represent (to forecast as well) as many as possible.

- How exactly does one represent the contribution of the specific drivers to growth, including the aggregation of their effects?

- How is it possible to represent the technological advance in systemic leaderships and what should be the character of representation of convergence?

[8] Hughes (2005a, 2005b) considerably elaborated the IFs approach.

3.2.1 Identification of Productivity Drivers

Figure 3 shows the theoretical framework structuring the IFs representation of economic growth. It does not show the forward linkages from growth to other parts of the model, such as demographic, socio-political and education modules that, in turn provide forecasts for future years of population and labor, savings and capital, and most of the drivers of various capital forms shown.

For ease of conceptualization, and in an effort to be consistent with the theoretical and empirical literatures, the framework identifies six forms of capital that shape productivity growth: human capital, social capital, institutional capital, infrastructure capital, natural capital, and knowledge base (knowledge stock or capital).[9]

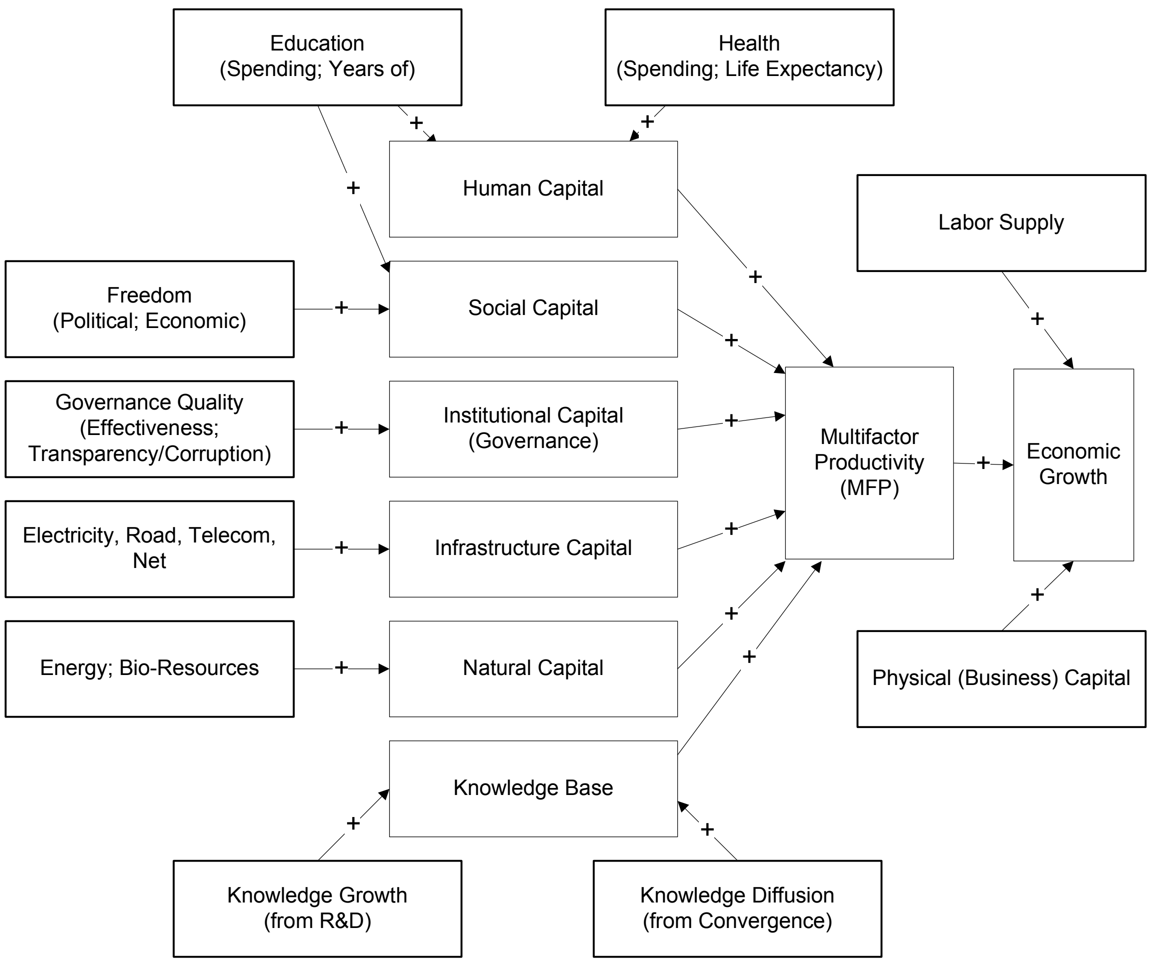

Figure 3. Multifactor Productivity in International Futures (IFs)

[9] The model code currently combines social and institutional capital and combines infrastructure and natural capital for reasons of historic development; the combination does not effect their contributions to forecasts of productivity and future revision will explicitly separate them.

Analysis of human capital typically focuses on education and health. Because the labor force carries their impact on productivity, typical indicators of human capital are stock measures.

Specifically, education of the population of age 25 and above is a common stock measure, in part because of the database that Barro and Lee (2003) developed and made available. Conceptually, a focus on the education of the population above age 15 might be better, especially for developing countries where most of those above 15 will be in the labor force. Life expectancy similarly reflects the stock of health in the general population, including the work force. DALYs (Disability Adjusted Life Years lost) might offer a richer stock measure of health, but IFs and other models typically do not forecast them. IFs uses life expectancy. As in most other cases, below, these measures are computed endogenously elsewhere in the model, but parameters that will affect their unfolding are available to model users for scenario analysis. [10]

The stock of education might not reflect its quality. The literature makes clear that the money spent on education does not always correlate highly with quality, depending of course on how it is spent, but it is still a useful quality proxy, especially above and below threshold levels of minimum need and potential overspending. Life expectancy presumably already represents the quality of health care so the argument for using expenditures on health care is more complicated. For instance, the distal driver formulations for mortality from the World Health Organization's (WHO) global burden of disease project include GDP per capita and education years, but not health spending or any other measure of health care system quality. Again, the relationship between spending and quality is therefore contested. But considerable literature on growth empirics does include health spending and IFs again therefore includes both stock and flow measures for health. The socio-political module assures that government spending and revenues remained connected (not precisely in balance) over the long-term and that government spending on transfers, military, education, health, R&D, and other (including administrative costs) involve trade-offs.

Turning to social capital, IFs contains no measure for trust, a common indicator of social capital. It is not at all clear how one can forecast changes in trust over time. IFs does contain measures for both political freedom/democracy and economic freedom. The socio-political module forecasts change in them, primarily from GDP per capita at PPP, and the model user can change them exogenously with multipliers. IFs bases its measure of economic freedom on that of the Fraser Institute and initializes it with their data. It

[10] Brock, Durlauf, and West (2003: see especially 285-286) argue that the first level of uncertainty in growth regressions (developing models of growth) is specification of theories, the second is specification of proxies, and the third is specification of growth processes across countries. They argue against exploring single theory models in favour of specifying categories of them and more generally favour a Bayesian approach to exploring drivers of growth down their tree of uncertainty. It is reasonable to favour a similar approach in the creation of models for forecasting and, although the approach here has limited geographic differentiation, it does specify multiple theoretical categories and explore multiple measures within each.

bases its measure of political freedom on the Freedom House (and includes another measure of democracy from the Polity Project).

Moving to institutional capital or governance, the literature gives most attention to the level of corruption. IFs bases its measure on Transparency International's corruption perception index. The World Bank's Governance Matter's project prepares six measures of governance. Empirical analysis in the IFs project (Hughes 2005b) suggests that its measure of governance effectiveness is the most powerful of the set with respect to growth forecasting and IFs includes it as well. There should be some attention to domestic conflict/stability in this category.

With respect to infrastructure, IFs looks to four separate measures: electricity generation, road network density, telecommunications density, and internet connectivity. The project intends to increasingly endogenize forecasting of all of these, tied in part to government expenditures. At this point only internet connectivity has significant endogenization.

Natural capital now receives a great deal more attention than ever before, specifically in terms of speculation about the impact of global warming and other environmental variables on economic prospects. Most of the prospective linkages are, however, little more than speculation. The one given most attention theoretically and empirically is energy availability. In essence, the issue is not availability, but price. As energy prices rise, some production capital effectively becomes obsolete. IFs therefore does link an energy price term, computed in the energy module, to the calculation of MFP.

Finally, endogenous growth theory looks to knowledge innovation and diffusion as a key, if not the dominant term in understanding productivity growth. Many analyses of institutions center on their protection of intellectual property so as to foster innovation, and many analyses of trade and finance understand them as routes to technological diffusion. In addition, of course, public spending on R&D contributes to both innovation and diffusion. IFs represents international integration, specifically trade openness, and R&D spending as drivers of productivity growth. The economic module provides the first and the socio-political module forecasts the second.

3.2.2 Contribution of Productivity Drivers

Identification of the drivers of MFP desired in the system and specifying how to forecast or to provide them exogenously, both discussed above, are the first steps. The next step is to specify the relationships between the drivers and changes in MFP over time.

The ideal approach to specification of the forecasting system might seem to be to build a full, simultaneously estimated system of relationships between all drivers and MFP – a fully econometric approach. There are, however, several weaknesses of such an approach that suggest serious consideration of a more structural, algorithmic approach.

First, estimations of the contributions of assorted drivers to change in MFP are far from stable and reliable. In part because of multicolinearity within systems of drivers, relatively small changes in data sets can significantly alter estimates. The summary appendix table by Durlauf, Johnson, and Temple (2005) across a large number of studies shows cases in which signs change and portrays much variation in whether or not results are statistically significant. They suggest (2005: 559) that such substantial parameter uncertainty "naturally leads to Bayesian or pseudo-Bayesian approaches to data analysis." The approach for the IFs system has been to examine a substantial number of studies and to extract parameterization for each driver used through an admittedly somewhat subjective, Bayesian inference process. Consistently with such an approach, it is expected that parameters will change over time with new data and studies.[11]

Second, the desired drivers in the system will evolve over time. With new theoretical insights, new data and new indicators, the representation in Figure 3 will change and elements will be added or removed. Again, it might seem that the ideal approach would be a bottom-up variation of growth accounting, in which incremental additions to productivity (or to a conditional convergence term) from various factors were summed to compute the overall rate of change in productivity. In reality, of the components in Figure 3 only a few, such as R&D spending (Barro and Sala-i-Martin 1999: 351-52), have had the benefit of such treatment. Moreover, there will almost always be missing factors in any such system, leaving the need for a residual or base calculation.

If a bottom-up, accumulation approach is questionable, an elasticity-like approach gains merit. Each term in Figure 3 can contribute positively or negatively, ceteris paribus, to overall productivity. Such an approach allows initial incompleteness with gradual elaboration and refinement.

It is typical to estimate coefficients for contribution of each driver of productivity relative to the initial condition or to the mean value across countries. There is, however, much reason to represent them for forecasting relative to an anticipated value specific to development level. Figure 4 represents such an approach. The relationship between GDP per capita and average years of education in adult populations is logarithmic. Relative to the best-fit function, Chileans have about one more year of education than would be expected and the Portuguese have about three years less education. Certeris paribus, the former situation ought to provide a boost to productivity and the latter a drag on it.

This conceptual approach looks in part back to the structural growth analysis of Chenery and colleagues (Chenery and Srinivasan 1989), which posits that common but not identical patterns of development accompany economic growth. It is also consistent with Sach's (2005) notion of clinical economics, in that a set of relationships like that in Figure 4 can help evaluate the strengths and weaknesses of countries relative to common patterns. We will return later to the notion of an overall, individualized development profile individual for countries.

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[11] The model system interface allows analysts to make changes easily.

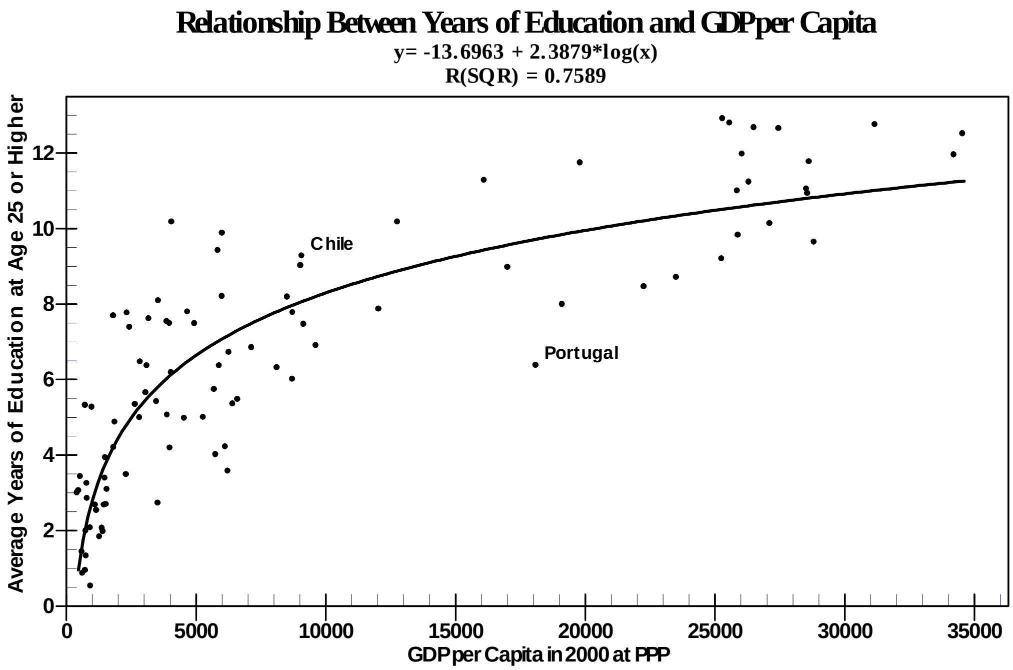

Figure 4. Example Relationship for Representing Productivity Driver Calculations

One problematic element of this approach is that literature-based parameter estimations for drivers of productivity do not rely upon such benchmark functions, but rather link changes in years of education or other drivers to growth contributions independent of structural expectation. Using such estimations relative to structural expectation is therefore something of a stretch. Conceptually, however, the approach here has logic and behavior that, we believe, outweighs that concern.[12] For instance, in the approach here, if years of education in Chile were to remain stable while its economic growth moved it to a GDP per capita of $20,000, the change over time in contribution of education to productivity would be negative rather than zero.

3.2.3 Treatment of Technological Leadership and Convergence

The neo-classical model anticipates conditional convergence of countries because, except for any contribution of ongoing technological growth, per capita growth in the richest countries will cease with diminishing returns to capital. Moreover, empirical estimation has found that the cost of imitation can be significantly less than that of innovation (Barro and Sala-i-Martin 1999: 269), so that growth late-comers should be able to adopt technology and catch up. Thus much empirical analysis of growth attends to the

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[12] In addition to the use of absolute units of change (such as one year education), it is fairly common to estimate contributions of drivers to productivity change in terms of coefficients relative to the standard deviation of the driver variable (such as average years of education or spending on R&D). In the approach here, we use units of standard error relative to the estimated function instead of standard deviation.

contributions of various factors to the rate of convergence, which many studies have identified as about 2 percent per year (Sala-i-Martin 1996; Durlauf, Johnson and Temple 2005: 586).[13]

There are substantial empirical problems with the convergence thesis, if it is stated in terms of poorer countries typically or most often growing faster than richer countries.[14] Although studies have shown such convergence in recent decades across states of the U.S., Japanese prefectures, regions in European countries, and OECD countries, it clearly does not characterize the quite dramatically divergent world generally over the last 200 years. Nor does it describe the divergence between African economic conditions and those of the rest of the world over the last 50 years.

Thus the treatment of convergence in forecasting must definitively produce both differential rates of convergence and the possibility of divergence. Baumol (1986) suggested conceptualizing three clubs of countries: a convergence club of industrialized countries, a middle income group including then centrally-planned countries, and the poorer, less-developed, diverging countries. De Long (1988) pointed out that significant selection bias exists in identifying members of a convergence club based on their end points rather than their initial conditions, and he did not find a convergence club.

Yet with respect to differential rates of convergence, there are theoretical and empirical reasons to believe that the required diffusion of technology requires not just improvements in education, governance or other drivers, but basic threshold levels that make imitation possible. Theoretically, diffusion requires capability for technology use, and societies with extremely low levels of GDP per capita or education are unlikely to find it possible to adopt or adapt modern, much less the most advanced technologies (de la Fuente 2002). Empirically, Liu and Stengos (1999) find no evidence of conversion below $1800 in initial per capita income; similarly, they find that the impact of education becomes more pronounced after a level of about 15 percent secondary enrollment (tapering off again at 75 percent). Durlauf, Johnson and Temple (2005: 619-624) reviewed a wide range of literature that has explored for and often found multiple convergence clubs

In spite of the complications around theory and evidence on convergence, the phenomenon is simply too important to ignore. The approach taken to it in International Futures (IFs) is unorthodox. First, instead of looking for a global coefficient of catch-up,

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[13] The extent of attachment to the 2 percent estimate, which is based largely on studies of more developed countries and regions within them (Barro and Sala-i-Martin 1999: 413), seems almost perverse when it implies that a country with an income per capita of $100 could close half of the initial gap between it and a country with an income per capita of $40,000 in about 35 years (2 percent of the gap each year), if only it would put in place the appropriate foundations for full-speed convergence. Compound growth rates for such a poor country of about 16 percent stretch the limits of credulity.

[14] The convergence literature (following Sali-i-Martin 1990 and Barro and Sala-i-Martin 1992) distinguishes between σ-convergence (when the systemic, for us global, dispersion decreases or time) and β-convergence (when poorer countries catch up with richer ones over time).

to be modified for specific countries by the various drivers mapped above, the approach posits that follower countries, ceteris paribus (by which we specifically mean in this case being on the paths of structural transformation mapped by cross-sectional analysis), tend to gain a technological premium in productivity growth as an advantage of their backwardness (Gershenkron 1962). Second, the approach posits that the maximum benefit of this premium accrues to countries that have GDP per capita of about $10,000. That level is near the point in the middle income range where the most rapid structural change—increases in life expectancy, literacy rates, democratization, and much more—has been completed and many dimensions of structural change slow substantially (see again Figure 4, which is typical; see Hughes 2001 for general discussion); it is above such a level that most empirical analysis has clearly found convergence. The approach posits that the convergence premium below that threshold diminishes, effectively disappearing at the lowest levels of GDP per capita. These assumptions together give rise to a stylized portrayal of a catch-up premium like that of Figure 5. The figure truncates the upper end of the figure at $20,000, but the forecasting model anchors the bottom of the downward sloping leg at the (changing) GDP per capita of the technological leader of the system.

Third, calibration of the model to the historic period between 1960 and 2000 (results discussed below) adjusted the final shape and peak of the catch-up representation. The premium is added to the technological growth rate of the system leader in calculating a base-line forecast of technological advance specific to each country. During the historic calibration period, annual technological advance of the leading country, the U.S., was exogenously set at productivity growth rates from the National Bureau of Economic Research and averaged about 1.5% over the time period (rates vary by sector and time period). The combination of the rate from the system leader and the technology premium would imply that a country at $10,000 per capita would have a base technology growth rate of about 2.3 percent per year.

Fourth, the base rate of productivity growth by country is then augmented or decremented by the driver set identified earlier, providing the final forecast of annual, country-specific productivity change within this algorithmic, structural system.

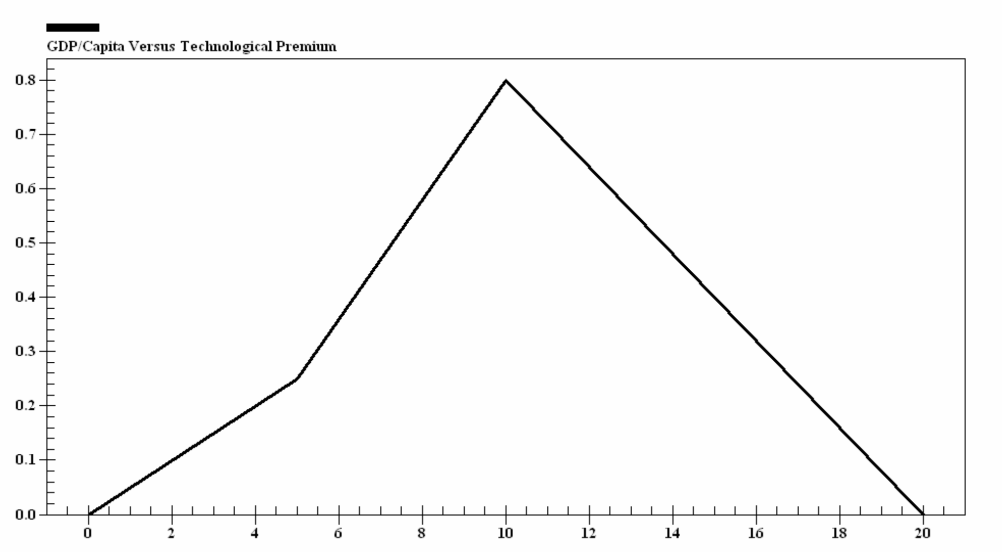

Figure 5. Stylized Technological Convergence Premium with GDP per Capita

3.3 Productivity in IFs: Equations and Parameterization

Core forecasting equations follow from the above structure. Following convention of the IFs project, variable names are those of the open-source computer code so that they facilitate its understanding and use. A Cobb-Douglas function produces value added (VADD) as a function capital (KS) and labor (LABS) by country or region (r) and sector (s), a cumulative technological growth factor (TEF), and a scaling parameter (CDA) computed in the first time step. The capital exponent CDALFS) and its labor complement are endogenous, and the capital share declines with GDP per capita.[15]

$$VADD_{r,s} = CDA_{r,s} * TEF_{r,s} * KS_{r,s}^{\boldsymbol{CDALFS_{r,s}}} * LABS_{r,s}^{(1-CDALFS_{r,s})}$$

$$where$$

$$TEF_{r,s} = TEF_{r,s}^{t-1} * \left(1 + MFPGRO_{r,s}\right)$$

The annual growth rate in multifactor productivity (MFPGRO) requires, of course, further explanation. As discussed above, there is a base rate (MPRATE) linked to systemic technology advance and a convergence premium. Specifically, the base rate sums the exogenously specified rate of advance in the leader (***mfpleadr***) and the premium computed for convergence of each country/region (MFPPrem), a function of GDP per capita at purchasing power parity (GDPPCP).

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[15] Estimation of the relationship for capital share used GTAP data, as do a number of other aspects of the model. For instance, the input-output matrices and factor shares for the model's six sectors are computed from the more disaggregated GTAP sectors. Most other economic data come from the World Bank's World Development Indicators, but a wide variety of data sources have served the project.

$$MFPGRO_{r,s} = MFPRATE_{r,s}$$
$$+ HumanCapitalTerm_{r,s} + SocialCapitalTerm_{r,s}$$
$$+ PhsyicalCapitalTerm_{r,s} + KnowledgeTerm_{r,s}$$
$$+ MFPCOR_{r,s}$$
where
$$MFPRATE_{r,s} = \boldsymbol{mfpleadr}_s + MFPPrem_r$$
where
$$MFPPrem_r = Func(GDPPCP_r)$$

On top of the base rate, multiple (currently four) terms additively affect/shift growth over time, each comparing country performance with structural expectations.[16] The model computes an adjustment or correction factor (MFPCOR) in the first year so as to make the overall growth rate initially consistent with recent historic experience for the country.

Turning to the four clusters of drivers discussed above, we discuss the human capital term illustratively. The annual change in MFP attributable to education (CngEduc) is the sum of two terms. The first compares the endogenous computation of average years of education (EDYRSAG25) of the population at age 25 or older (responsive, to all of the factors represented in the education module) minus the expected value of the same variable computed from a cross-sectional function (ExpectedEDYRSAG25) like Figure 4. As will be discussed below, this driver variable should be changed to education above age 15 and perhaps to education between the ages of 15-60 or 15-65. The second term similarly compares the portion of the GDP that government directs to education (g=EDUC) with the expected value of the same ratio. The contribution to the human capital from health is directly comparable. Four parameters from the literature (in bold face) convert differences from expected values into shifts of productivity growth.

$$HumanCapitalTerm_{r,s} = CngEduc_r + CngHlth_r$$
$$CngEduc_r = (EDYRSAG25_r - ExpectedEDYRSAG25_r) * \boldsymbol{mfpedyrs}$$
$$+ \left(\frac{GDS_{r,g=EDUC}}{GDP_r} - Expected \frac{GDS_{r,g=EDUC}}{GDP_r} \right) * \boldsymbol{mfpedspn}$$
$$CngHlth_r = (LIFEXP_r - ExpectedLIFEXP_r) * \boldsymbol{mfplife}$$
$$+ \left(\frac{GDS_{r,g=Health}}{GDP_r} - Exppected \frac{GDS_{r,g=Health}}{GDP_r} \right) * \boldsymbol{mfphlspn}$$

Hughes (2005a) described the parameterization of the forecasting system, drawn from an extensive literature of estimations and stylized facts on productivity. Illustratively,

[16] Not shown, there is also an exogenous additive parameter (mfpadd) allowing users to intervene and change growth paths for any country/region. The presentation of equations here omits a number of such "exogenous handle" parameters and terms not central to the exposition.

parameterization considered years of education and educational expenditures as a pair. Analyses in the literature include:[17]

- Barro and Sala-i-Martin (1999: 431) reported that a 1 standard deviation increase in male secondary education raised economic growth by 1.1% per year, and a 1 standard deviation increase in male higher education raised it by 0.5%. Barro (1999: 19-20) reported that one extra year of male upper-level education raised growth by 1.2% per year.

- Chen and Dahlman (2004: 1) concluded that a rise of 20% in average years of schooling raises annual growth by 0.15 percent and that an increase in average years by 1 year raises growth by 0.11 percent.

- Jamison, Lau, and Wang (2003: 4) used the Barro-Lee measure of average years of school for males between 15 and 60, but concluded that the "effect was small."

- Bosworth and Collins (2003: 17) argued that each year of additional education adds about 0.3% to annual growth.

- The OECD (2003:76-78) found that one additional year of education (about a 10% rise in human capital) raised GDP/capita in the long run by 4-7%.

- Barro and Sala-i-Martin (1999: 432) concluded that increasing education spending as a portion of GDP by 1.5 points (one standard deviation) raised growth by 0.3%.

- Balacci, Clements, Gupta, and Cui (2004: 24) found that raising education spending in developing countries by 1% a year and keeping it higher added about 0.5% per year to growth rates. They also found that 2/3 of the affect of higher spending is felt within 54 years but the full impact shows up only over 10-15 years.

Possible conclusions and stylized facts for the IFs project are:

- First, there is reason to use average years of education in the population above 15 years of age as the key driver, switching away from current IFs use of education in the population above 25 years of age. The former has increasingly become the focus of studies around education and there is theoretical logic for using it: additional education seems likely to affect productivity only as those receiving it move into their prime working years. Fortunately, the cohort structures of the

[17] Mankiw, Romer and Weil (1992) was one of the early extensive empirical analyses of growth. They found that the Solow model was generally correct and useful, but that a CES formulation improved performance. We stay here with the Cobb-Douglas version because it is so widely used. They also found that human capital accumulation, which they tapped with secondary school enrollment was very important and that OECD countries behaved differently than low income ones.

population and education submodels of IFs will make future computation and use of that variable relatively straight-forward.

- Second, although Barro's work suggests that male education is more important than that of females in affecting economic growth, there is uncertainty about this conclusion. Thus, for reasons beyond political correctness, it makes sense to use general years of education, not just levels for males.

- Third, it appears that 1 additional year of education may raise the growth rate by about 0.1-0.3%.

- Fourth, higher education spending as a portion of GDP appears to have an independent impact on growth; some studies suggest that it captures, in part, quality of education. The magnitude of the effect appears to be approximately a 0.3-0.5% increase in growth for an additional percent of GDP spent on education.

Overall the literature suggests that years of education generate additional growth at the rate of 0.1-0.3% per year of education and the latter generates additional growth at the rate of about 0.3-0.5% per extra percent of GDP allocated to education. Both parameters were set on the low side of these ranges, 0.1 and 0.3, respectively. Conservative parameterization was a general rule because many studies look at single or small sets of parameters and may overstate their importance within a more fully integrated set.

Similarly, parameterization treated life expectancy and health spending as a pair. Analyses in the literature include:

- Barro and Sala-i-Martin (1999: 432) found that an increase in life expectancy by one standard deviation, which they calculated to be 13 years in the 1965-75 period) raised economic growth by 1.4 percent per year.

- Bloom, Canning, and Sevilla (2001: 5 and 16) found that a rise of 1 year in life expectancy raises output by 1-4%.

- Baldacci, Clements, Gupta and Cui (2004: 25:26) concluded that increasing health expenditure by 1% of GDP raises economic growth by 0.5% over 15 years; in their analysis the impact is basically the same as that of a 1% rise in education spending.

Possible conclusions and stylized facts for the IFs project are:

- First, as with years of average income, life expectancy is more of a stock than flow variable and should be a key driver. Yet by addressing immediate human illness, health spending might more quickly affect productivity than education spending concentrated in early years of life is likely to affect it.

- Second, the Barro and Sala-i-Martin (1999) work suggests that a year of life would raise economic growth by just over 0.1%. If the full affect of the result found by Bloom, Canning and Sevilla (2001) is estimated to accumulate over 10-15 years, their result is of the same rough order.

- Third, it appears that an additional 1% of GDP spent on health might raise economic growth by as much as 0.5%, comparable to or somewhat greater than the effect for education spending.

Overall, the IFs parameterization with respect to an extra year of life expectancy is quite conservative at 0.1, as is the parameterization with respect to 1% of extra spending at 0.3.

3.4 Recognized Weaknesses and Important Issues

The endogenous productivity and growth forecasting system of IFs is far from perfect and there are a number of potential and actual weaknesses. With respect to the formulation, we documented above the unorthodox and admittedly somewhat ad hoc treatment of convergence. The treatment of impact of productivity drivers based on their deviation relative to cross-sectionally estimated functions is also unusual. The strictly additive specification of growth contributions (or costs) of productivity drivers misses interaction effects among the drivers.

With respect to parameterization, obtaining Bayesian-like numbers from the literature, where estimations were often made based on significantly different formulations leaves much to be desired. Almost certainly, especially in light of the structural transformation perspective that underlies the approach, there should actually be decreasing marginal returns to drivers when their values significantly exceed the typical ones of the cross-sectional, structural estimation (very high levels of education in many sub-Saharan countries might produce an entitled bureaucratic elite like that of Egypt rather than additional growth). In contrast, values that fall significantly below those typical at given levels of development might have even greater costs (the O-ring effect so-named after the Shuttle Challenger disaster).

Many of these weaknesses are, of course, not unique to the IFs approach, except insofar as the IFs approach is itself unusual in taking the big step of building a substantial, integrated approach to endogenizing productivity in a forecasting model. Once again, the motivation of the model is to provide a long-term system with a broad range of drivers of productivity and therefore many access points for representing both endogenous linkages of the various modules (including feedback systems linking demographics, economics, education, health, and socio-political modules) and exogenous handles for manipulation and exploration by model users.

Both the weaknesses and the motivation make the next logical step one of exploration of model behavior: historically, in forecasting, and in the face of interventions. How well does the system perform?

4. System Performance

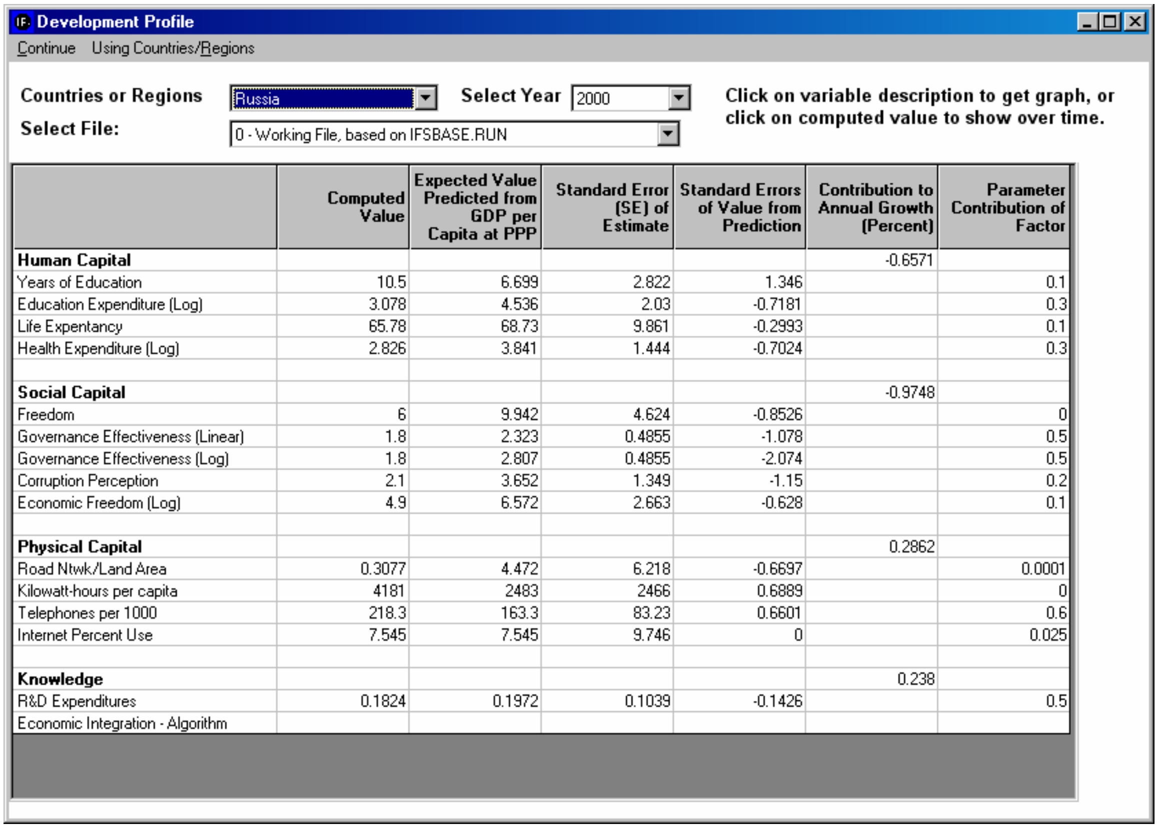
There are a variety of techniques for assessing the quality and performance of forecasting models, which is definitely an art rather than a science. In general techniques fall under the rubric of verification, validation, and accreditation (VVA), see Hodges and Dewar (1992), Arthur and Nance (1997), and Sargent (2000) generally and Hughes (2006) with respect to IFs. Four techniques can be of use with respect to the productivity system: subjective reasonableness, historic analysis, forecasting analysis, and intervention analysis.

4.1 Subjective Reasonableness

This presentation of the theoretical and empirical foundations of the IFs approach has throughout been directed at making possible assessment by others of the reasonableness of the approach. Here we turn to the numbers. The first place to look is at the impetus that each of the drivers gives to productivity in the base year of the model (currently 2000). Doing so is a kind of face validity analysis, an approach in social science that simply involves consideration of whether a measure, to a reasonably expert observer, "looks like" it is tapping what we want it to assess.

The Development Profile (see Figure 6) is one of the windows in the IFs interactive interface. The profile is a form of the clinical analysis that Sachs (2005) called for with respect to assessing the specific strengths and weaknesses of a country with respect to its development prospects. The rows correspond to the productivity drivers of the system, grouped into the four current categories of the IFs model code, but representing the six categories of Figure 3 (because the effects are additive, the grouping facilitates conceptualization but does not affect results).

The first numerical column shows the value initialized for the base year of the model's forecasts. The second shows the value expected from cross-sectional analysis while the third indicates the size in units specific to the variable of a standard error of estimate for that function (equivalent to a standard deviation relative to a mean). The fourth column indicates the number of standard errors that the computed value (actual in the base year when data exist, computed thereafter) varies from expected value. That value is indicative only. With few exceptions, the actual contribution of each term to a shift in the productivity function depends on units specific to the driver (such as years of education or life expectancy and percentages of GDP spent on education or health). The last column contains the parameter that converts the units of deviation from expected values into shifts in productivity; earlier text discussed those for the human capital category. The parameters times the units of deviation, summed across members of the category, produce the percentage contributions to annual productivity growth shown in the penultimate column.



	Computed Value	Expected Value Predicted from GDP per Capita at PPP	Standard Error (SE) of Estimate	Standard Errors of Value from Prediction	Contribution to Annual Growth (Percent)	Parameter Contribution of Factor
Human Capital					-0.6571	
Years of Education	10.5	6.699	2.822	1.346		0.1
Education Expenditure (Log)	3.078	4.536	2.03	-0.7181		0.3
Life Expectancy	65.78	68.73	9.861	-0.2993		0.1
Health Expenditure (Log)	2.826	3.841	1.444	-0.7024		0.3
Social Capital					-0.9748	
Freedom	6	9.942	4.624	-0.8526		0
Governance Effectiveness (Linear)	1.8	2.323	0.4855	-1.078		0.5
Governance Effectiveness (Log)	1.8	2.807	0.4855	-2.074		0.5
Corruption Perception	2.1	3.652	1.349	-1.15		0.2
Economic Freedom (Log)	4.9	6.572	2.663	-0.628		0.1
Physical Capital					0.2862	
Road Ntwk/Land Area	0.3077	4.472	6.218	-0.6697		0.0001
Kilowatt-hours per capita	4181	2483	2466	0.6889		0
Telephones per 1000	218.3	163.3	83.23	0.6601		0.6
Internet Percent Use	7.545	7.545	9.746	0		0.025
Knowledge					0.238	
R&D Expenditures	0.1824	0.1972	0.1039	-0.1426		0.5
Economic Integration - Algorithm						

Figure 6. A Development Profile Example: Russia.

Figure 6 illustrates the results of such analysis for Russia. It indicates that human capital is retarding productivity growth by about 0.66 percent. Although years of education in Russia are well above expected values and therefore make a positive contribution, life expectancy falls significantly short of expectations as do government expenditures on education and health. Similarly, social capital (better described as institutional capital or governance) contribute negatively, nearly 1 percent. Because of very mixed empirical analyses, the parameter of the freedom or democracy term is zero and Russia's more authoritarian than expected system is not posited to be a drag on productivity. But all other terms, specifically governance effectiveness, corruption perception, and economic freedom or liberal orientation work against it. The assessment suggests that both physical capital and knowledge categories contribute relatively smaller, positive impetus to productivity.[18]

The reader should make her/his own judgment as to whether the assessment of Russia has face validity. To further facilitate such judgment, Table 1 shows the computed contributions of each of the four clusters for several additional countries. To keep the

[18] The internet usage term makes no contribution; absence of data leads to the computation of an initial condition using the cross-sectional function and therefore to no gap between computed and predicted. The economic integration term is computed in a more substantial and algorithmic process (see again Hughes 2006) and its contribution cannot be displayed in the categories of Figure 6.

sample generally random, countries are the first alphabetically for each initial letter of the alphabet through "K".

	Human Capital	Social Capital	Physical Capital	Knowledge
Afghanistan	-1.01	-0.16	-0.17	0
Barbados	-1.76	-0.15	-0.02	0
Cambodia	-1.04	0.01	-0.33	0
Denmark	0.93	0.27	0.75	-0.01
Ecuador	-0.07	-0.44	0.05	-0.1
Fiji	-0.06	0.02	-0.18	0
Gabon	-1.92	-0.54	-0.82	-0.31
Haiti	-1.32	-0.55	-0.27	-0.01
Iceland	0.47	0.34	1.08	0.24
Jamaica	1.25	0.32	0.63	-0.15
Kazakhstan	-0.38	-0.28	-0.06	-0.09

Table 1. Productivity Contributions of Four Clusters for Sampled Countries,

The reason that the knowledge cluster in Table 1 contributes so little is simply that there are no R&D expenditure data for most developing countries. Some other indicator perhaps might replace that variable. Because, however, the driver contributions work relative to initial conditions, a country that increased or decreased its R&D in the forecast period relative to the initial computation of R&D from the function would influence its productivity. This is one of the advantages of using a formulation based on coefficients and relative change rather than trying to build productivity bottom up via growth accounting.

Interestingly, the overall magnitudes for the human capital contributions (for the listed countries mostly negative ones) exceed those for physical capital, which in turn tend to be larger than those for social capital. That might suggest some reevaluation of parameterization. It could also be a result of tighter cross-sectional patterns in some categories than other; as discussed for R&D, the forecasting results are heavily sensitive to change rather than initial productivity impetus.

4.2 Historic Analysis

Fit of a forecasting model to an historic period is a common primary test of its performance. Figure 7 shows the fit of IFs forecasts based in 1960 to historic data through 2000. It shows world GDP as well as that for OECD and non-OECD countries separately. The fits are obviously fairly good. Moreover, much of the more rapid growth of forecasts in the last few years relative to data is attributable to data shortages in the comparison set. Specifically, there are data missing after 1997 for Taiwan, accounting for most of the global and non-OECD gap. In addition, data for Cuba, North Korea, Myanmar/Burma and Somalia are missing.

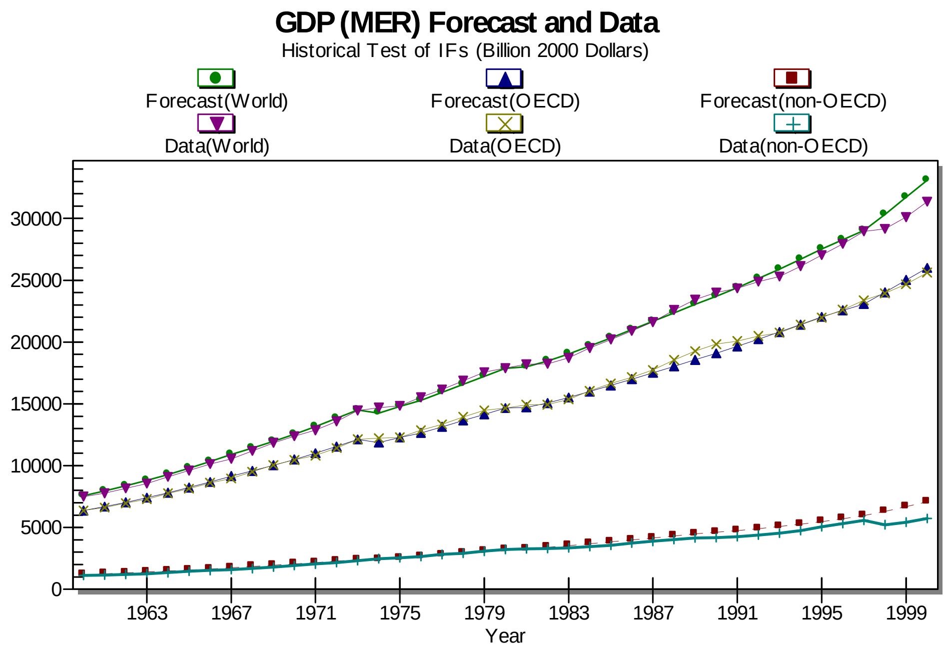


Figure 7. IFs Historic Forecast Relative to Historic Data

Aggregations often conceal much, however. Figures 8 and 9 break down the developing countries into two sets and show the same comparison. In Figure 8, the developing East Asian countries, dominated in size by China fit fairly well (again the absence of Taiwan in the last years weakens that fit). But the Latin American and Caribbean countries fit very well only until about 1980 and then the model fails to reflect a shift downward in historic performance as indicated by the data (that is, the "lost decade" of the 1980s does not appear lost in the model.

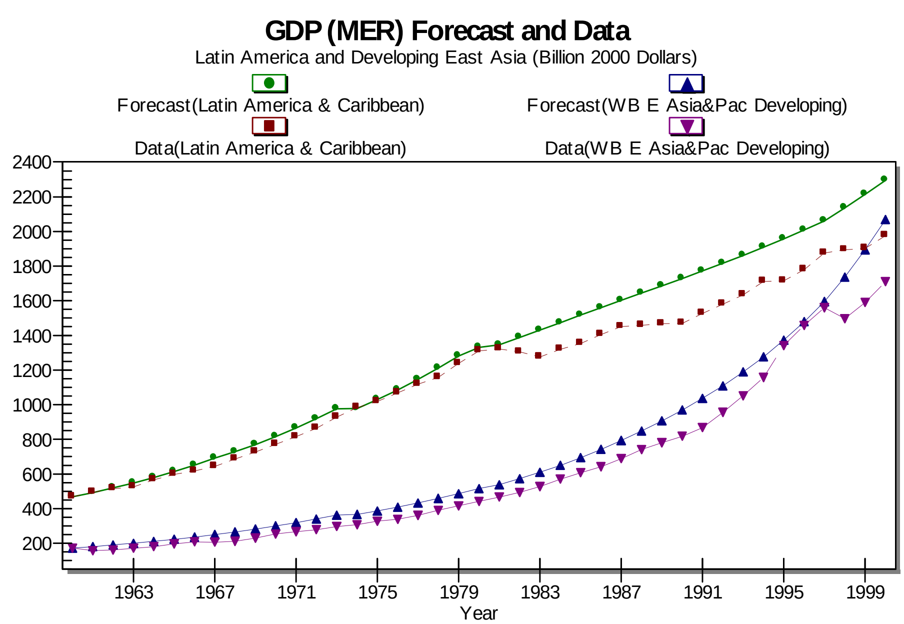


Figure 8. IFs Historic Forecast Relative to Historic Data (Latin America and East Asia)

Figure 9 shows a similar phenomenon with respect to quite a good fit throughout for Sub-Saharan Africa, but for South Central Asia a continuation of forecast growth in the 1980s when the data indicate a downward shift in it.

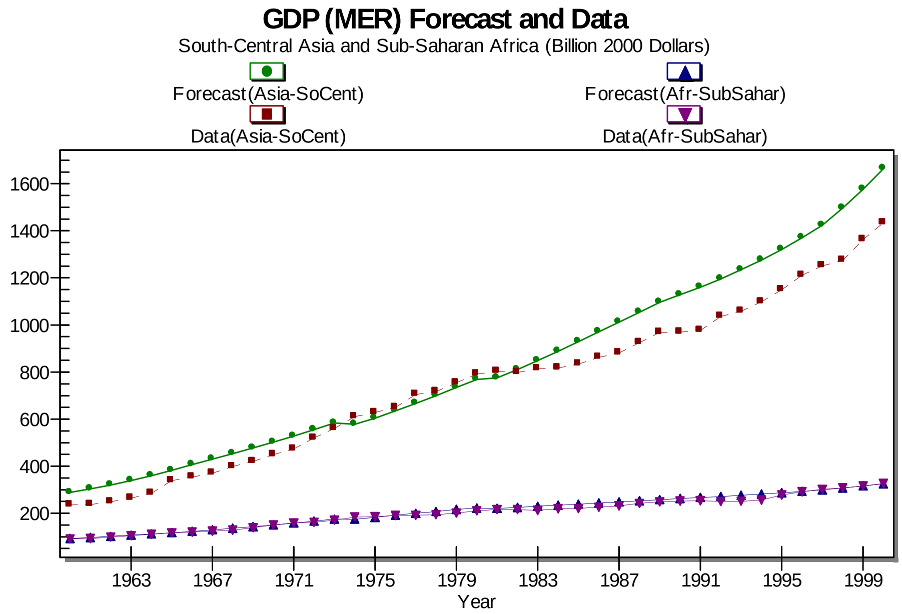


Figure 9. IFs Historic Forecast Relative to Historic Data (Africa and South Central Asia).

It would be unreasonable to expect that a model of so many human subsystems across 182 countries and 41 years would reproduce history without errors and or corrective interventions. The practice in the IFs project is to keep the interventions relatively small in number and to document and explore them so as to understand the system's strengths and weaknesses. They merit brief discussion here. We can usefully divide them into two categories. Foundational interventions address issues in modules such as demographics and energy that ultimately drive the production function and economic change. If those drivers are not being forecast relatively well, there is, of course, no hope that the economic forecasts will be reasonable. The second category of interventions addresses economic growth directly. Those are more problematic for the productivity discussion here.

4.2.1 Foundational Interventions

The bulk, but by no means all of the foundational interventions compensate for the model's inability to anticipate a variety of events that political decisions highly affect. In particular, systemically reshaping periods such as the oil shocks of the 1970s and the breakdown of communism in the late 1980s pose great problems for endogenous representation. A model like IFs could create structures that would generate such shocks, but those structures would tend to be ad hoc and would not give confidence that the model would forecast such events going forward.

Demographic System Interventions

On a global basis interventions introduced (1) a gradual slowing of the rate of downward shift in the relationship of GDP per capita and fertility and (2) a gradual slowing of the rate of upward shift in the relationship of GDP per capita and life expectancy in more developed countries.

On a geographically specific basis, interventions in initial fertility and mortality rates for China compensated for the distorting effects of the Great Leap Forward in initializing demographic data. Further, a multiplier introduced the sharp, politically-driven movement of Chinese fertility downward after 1980. Similarly, multipliers introduced a slower, also politically-shaped movement of Indian fertility downward over the entire period, a downward movement in US fertility early in the period (the ending of the post-WWII baby boom), and a politically/culturally based upward movement relative to endogenous forecasts of fertility in North Africa and the Middle East.

Finally, net migration rates were introduced exogenously for all countries because the model does not have a structure that generates changes in those patterns, including the wide-spread acceleration of rates in the last two decades of the century and conflict-related flow patterns.

Energy System Interventions

On a global basis a set of interventions significantly shaped (1) the major expansion of oil production in OPEC countries in the 1960s, (2) the contraction of that production in the 1970s, and (3) some of the aftermath of that contraction including the expansion of North Sea production. Political interactions significantly shaped each of those historically, especially the last two. Although the energy model automatically generates some tightening of energy markets in the 1970s and the movement of the United States past its Hubbert's curve peak (later than it actually occurred), it does not reproduce the oil shocks of the 1970s without intervention.

Political-Social Interventions

Because of the economic freedom variable's direct role in the productivity calculation, mostly relatively small interventions were made via multipliers to the otherwise endogenous evolution of the variable for China, India, the US, Sub-Saharan Africa, Latin America and the Caribbean, North Africa and the Middle East, and the Transition Economies. The interventions generally accelerated economic liberalization in the last two decades relative to the first two, at regionally-specific time points reflecting political choices.[19]

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[19] The economic freedom function for 1970, used in the historic run, was badly estimated and needs to be redone. Currently, interventions retard liberalization in early years and then relax the restrictions; after re-estimation the pattern will more simply be liberalization in later years.

4.2.2 Economic Interventions

More directly economic interventions pose potentially greater challenge to the productivity formulation at the core of this discussion. One subset presents only limited challenge. The general interventions below specify the rate of growth of the technological leader and the possibility of substantial change in political-economic orientation (like that of China in recent decades). The model does not pretend to forecast either. The second subset, however, direct growth interventions, clearly carries the possibility that the productivity formulation and/or parameterization is significantly flawed.

Economic Interventions: General

On a global basis, intervention set values for productivity rates of the US as designated systemic technology leader. Further, in the last two decades interventions relaxed protectionism globally and introduced a general export promotion orientation.

A small set of interventions targeted China specifically in the last two decades, namely a high savings/investment rate and higher shifts in export promotion and protection reduction than the global values.

Economic Interventions: Growth Specific

If the interventions listed to this point had created a perfect (or at least very solid) set of drivers for productivity and if the productivity formulation were in perfect working order, no further interventions would have been necessary. In fact, however, some were made.[20] In each case an additive (positive or negative) parameter was adjusted.

Four interventions targeted oil producing countries. One reduced Algerian growth rates across the entire time horizon, the only such intervention prior to 1980. The aftermath of the war with France (ending in 1962), the oil shock period and the insurgency after 1992 all certainly contributed to slower growth than would have been expected. Two additional interventions significantly reduced economic growth in Iran and Saudi Arabia after 1980. A combination of the fall of oil prices and drops in production and export volume help explain declining growth. Similarly, an intervention after 1990 reduced Iraqi growth. The Iran-Iraq war and subsequent conflicts help explain that intervention.

One intervention decreased growth in the countries of the Former Soviet Union after the collapse of communism. The model could not anticipate that.

The remaining interventions are the most problematic. In Asia, Chinese growth was raised 1.5 percent annually after 1980 and Indian growth was actually raised 3.0 percent annually. The former might be expected because some analysts believe numbers have been inflated and those who believe the numbers also find them complicated to explain

[20] A total of 71 parameter changes (global, regional, country-specific, or country and sectoral) were made for the historic run, other than the 182 changes made to specify net migration rates for all countries. Of those 25 were directly in the economic module. Of those, 14 were growth specific.

(much less to have predicted). The second suggests the need for a full review of Indian growth drivers and the formulation as it forecasts for India.

Also in Asia after 1980, interventions reduced Japanese growth by 1.5 percent and Taiwanese growth by 3 percent. Both interventions suggest that the formulation may not be fully capturing the phenomenon of slowing growth as very rapidly growing countries (sometimes referred to as NICs or Newly Industrialized Countries) catch-up with leaders.

In Sub-Saharan Africa, growth after 1980 was reduced by 2 percent annually. This need may again, as with some of the countries above, reflect in part the inability of the model to anticipate conflict. It is possible that if a conflict measure were introduced exogenously and the term were entered into the productivity/growth calculation, the model would then calculate some significant growth adjustment.

The remaining interventions were in Latin America and the Caribbean. One reduced growth in South America by 1 percent after 1980 and another reduced growth in the Caribbean by 4 percent. Two others specifically reduced growth in Brazil by 3 percent and that in Mexico by 2 percent. As indicated earlier, even these reductions did not fully capture the downward shift in growth of the region in the 1980s. Debate on why growth collapsed continues, of course, in the development community.   Candidate explanations come from opposing political orientations. Some attribute the problems to neo-liberalism and accompanying policy such as IMF conditionality. Others attribute them to failure of countries to liberalize their economies and pursue global trade and financial connections with the aggressiveness of Asian developing countries.

With respect to the performance of the IFs model, there is one other very important explanation, also relevant to Africa. The model does not calculate the build-up of debt during the oil shock period and the aftermath of that for debt-burdened countries. Its international financial representation forces policies that adjust exchange rates (the equivalent of floating exchange rates) and even governmental fiscal policy so as to maintain equilibrating processes in international and domestic economies. It will almost certainly be necessary to introduce the possibility of substantial overshoot and collapse processes around debt to capture better the downturns of the 1980s in Latin America and Africa. This is not a weakness of productivity formulation, but of financial formulation.

4.2.3 Summary Assessment

It is unlikely ever to be possible for a system of models like IFs can forecast the 1960-2000 period for 182 countries with considerable accuracy only from endogenous specifications. The analysis above suggests some of the problems and it only focused on regional patterns of behavior. Some countries behave even less well than the regions in the historic forecast (and, of course, some behave better).

The good news is that many and perhaps most of the failures in the IFs model to capture historic patterns closely derive from problems with forecasts of foundational drivers and missing elements of the system; over time and with development, those continue to improve. The bad news is that, until those foundations perform very well, it is difficult truly to test the productivity and growth formulations within IFs.

Overall, different readers will probably judge the results of this analysis quite differently. The goal here was to provide the basis for doing so.

4.3 Comparative Forecasting Analysis

Economic growth forecasts reflect assumptions about labor force and savings/capital accumulation, not just about multi-factor productivity. Base case forecasts of population and labor force growth do not tend, however, to differ much across forecasting projects. And investment rates tend also not to be dramatically different. Thus longer range economic forecasts, to the degree that they differentiate these drivers as opposed to extrapolating more simply, differ primarily in their assumptions about productivity advance.

Table 2 compares three such forecasts through the year 2030, as far into the future as most economic forecasters are prepared to look. Using the LINKAGE model, the World Bank regularly produces economic forecasts in its annual *Global Economic Prospects* and extended its horizon from 2015 to 2030 in the 2007 edition. For the energy forecasting of the U.S. Energy Information Agency, Global Insight, Inc. has also provided economic forecasts through 2030. Although there are slight variations in the way the studies treat time periods and regional groupings (for the table the IFs regions are identical to the World Bank), each source looks to purchasing power parity for its regional numbers and the forecasts are quite comparable.

	GDP Growth Rate 2008-2030		
	World Bank	Global Insight/EIA	IFs Base (PPP)
World	2.9	3.8	3.7
High Income	2.4	2.6	2.6
Developing Countries	4.0	5.0	4.8
WB East Asia and the Pacific	5.1	5.5	5.4
WB Europe and Central Asia	2.7	4.4	3.6
WB Latin American & Caribbean	3.0	3.8	3.3
WB Mid East and North Africa	3.6	4.2	4.7
WB South Asia	4.7	5.5	5.1
WB Sub-Saharan Africa	3.3	4.4	4.4

Table 2. Three Forecasts of GDP Growth Rates

Sources: World Bank 2007: 3 (Table 1.1); US DOE 2006: 12 (Table 2); IFs Version 5.45.

Notes: The Global Insight/DOE EIA forecasts are for the 2003-2030 period and countries within regions are weighted at PPP; the regions are not identical to the other sets and their value for Asian developing countries was assigned to both East Asia and South Asia. The World Bank global forecast uses PPP weights.

Table 2 shows IFs forecasts global growth of 3.7 percent, nearly a percent higher than that of the World Bank and just below that of Global Insight. The major differences between IFs and the World Bank are not in the high income world, but in developing countries. IFs forecasts are relatively highest for the Middle East and North Africa, driven in substantial part by the expectation of high energy revenues. They are also at the high end of the set of three for Sub-Saharan Africa, influenced by the recent acceleration of economic growth in the region.

Initial growth rates for IFs depend generally on recent growth rates. The data preprocessor of IFs looks to the last 13 years of GDP data (now available through 2005), weighting the last seven years twice as heavily as the previous six. As indicated in the equations earlier, the initial growth rate estimate leads to the calculation of a correction term that adjusts the values coming from the calculation of MFP. It is useful to consider the magnitude of those correction factors, because they may be suggestive of some of the key sources of uncertainty in forecasting further into this century.

On a global basis the correction factor, weighted by each country's economic size, averages -0.024 percent. It is, as it should be, near zero. Yet again, however, geographic averages conceal much. For OECD countries, the correction factor is -0.32 percent. That is, it was necessary to reduce the calculations of MFP in OECD countries by an average of nearly 1/3 of a percentage point to bring their initial growth rates down to the pattern extracted from the last 13 years. That could mean that the productivity function is overestimating their patterns of growth, it could mean that the historic growth pattern has fallen below the rates that they are capable of going forward, or the correction could indicate some of both. To the degree that the productivity formulation in IFs is adding any information to forecasting capability, it suggests that forecasts based almost entirely on past performance (an extrapolative forecast) may be somewhat underestimating economic growth potential of these countries.

In contrast, the correction term for the GDP weighted-average of non-OECD countries was 1.21 percent, suggesting that a purely extrapolative forecast could be overestimating their future growth relative to one based more purely on productivity driver analysis. More specifically, the numbers for South Central Asia, developing East Asia and the Pacific (dominated by China), and Sub-Saharan Africa were 1.78 percent, 2.44 percent, and 2.58 percent respectively. With respect to Sub-Saharan Africa, the commodity-fueled boom of recent years might be leading to extrapolative forecasts that are too high. In contrast, the correction term for Latin America is -0.61 percent.

The IFs forecasts build in a large extrapolative element by computing the correction factor relative to recent past growth rates and continuing to add it to the forecasts from the production function over time. Although IFs very gradually phases the correction factor out by mid-century, it is possible that it should phase it out more quickly or even eliminate part of it immediately as being too responsive to data and not allowing the underlying productivity formulation to sufficiently drive growth. Doing so would, for the most part, bring the IFs forecasts a bit closer to those of the World Bank.

4.2 Intervention Analysis

The various approaches to this point for looking at the quality of IFs forecasts have provided relatively little insight into the behavior of the system in the face of interventions using specific drivers. As indicated at the beginning of this paper, the reason for trying to build forecasts with endogenously specified productivity is to address policy-relevant questions, which tend to be what-if in character. For example, what if a country spends more education or R&D? What if it reduces the level of corruption or moves towards freer markets?

Some results from a much more extensive study with IFs of the future of global poverty (Hughes, Irfan, Khan, Kumar, Rothman, and Solórzano 2008) can illustrate the potential for such analysis and, in fact, give some information about the leverage that may be tied to the different productivity drivers. Table 3 shows the number of people living in extreme poverty (on less than about $1 per day) in the Base Case forecast of IFs and also in the case of a number of individual interventions and a combined domestic package of interventions. The broader study considers also a set of interventions based on international policies.

	Extreme Poverty (Millions)					
Scenarios	**Developing 2015**	**SS Africa 2015**	**S Asia 2015**	**Developing 2050**	**SS Africa 2050**	**S Asia 2050**
Base Case	633	258	235	298	246	25
Fertility Reduction	627	252	235	221	169	25
High Fem Labor	633	258	235	298	246	24
High Investment	661	273	245	304	258	20
High Education	630	257	234	280	230	23
High Health Exp	632	258	235	289	240	23
High Govt Effect	622	256	230	274	230	21
Low Corruption	631	258	234	273	227	22
High Econ Free	630	257	233	283	236	22
High Infrastructure	632	258	235	285	236	24
High Renewable	633	258	235	295	244	24
High R&D	632	258	234	299	248	24
Low Protection	630	258	231	300	252	21
High Transfers	614	243	235	255	207	25
All Domestic Combined	610	248	231	94	74	9

Table 3. Poverty Intervention Analysis Using IFs

Poverty forecasts are fundamentally tied to forecasts of GDP. Income distribution affects them, but tends to change slowly and relatively little, so that in the long run especially economic growth is critical. Table 3 therefore suggests a number of conclusions not just about poverty, but about the linkages between the interventions listed and economic growth. First, many interventions increase growth and decrease poverty via enhancements of productivity. Second, most of them are fairly slow to work, so that their ability to decrease to poverty between 2008 and 2015 relative to the base case is modest. Third and related, in the longer term they can have major affects on productivity, growth, and poverty.

More extensive intervention analysis of this type, in comparison with results from other means of studying them, will use and test the productivity formulation of IFs in a manner that will greatly complement the analysis introduced here. Studies in the series on Potential Patterns of Human Progress will do exactly that.

5. Conclusions

Policy-oriented economic forecasting requires attention to the impact of such policies on productivity and economic growth. Relatively little longer-term economic forecasting, which would greatly benefit from such attention, attempts endogenously to represent multiple elements that drive productivity.

The International Futures (IFs) modeling project has developed an approach to endogenizing productivity for forecasting purposes within an extensive system of models, attempting to be consistent with a variety of advances in theoretical and empirical foundations. The approach combines attention to technological change in a systemic leader with a non-linear representation of convergence potential and additive shifts in productivity tied to a wide range of drivers in multiple categories. Most of the drivers in the productivity formulation are, in turn, endogenously determined in other modules of the larger system of models, but model users additionally can manipulate them for what-if analysis.

In spite of many weaknesses in the approach, it produces forecasts for 182 countries or aggregations of them across a substantial historical period (1960-2000) and well into the century (with and without interventions related to the drivers) that are reasonably consistent with expectations and with other work. As a system, it is fundamentally unique in its ability to explore long-term national and global economic growth and its consequences under a wide range of alternative assumptions.

Much remains to be done. Enhancements to the larger system can considerably improve the drivers that enter the productivity formulation and also the forward linkages from economic growth to other modules. Refinements to the structure of the productivity formulation itself, addressing issues around saturation effects of policy-driven drivers and around interactions across them remain possible. Improvements in the parameters of the formulation, perhaps based on estimation schemes more consistent with its structure, will be useful.

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