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WORKING PAPER 2005.05.24.a

FORECASTING PRODUCTIVITY AND GROWTH WITH INTERNATIONAL FUTURES (IFs) PART 1: THE PRODUCTIVITY FORMULATION

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May 2005

Note: If cited or quoted, please indicate working paper status.

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Forecasting Productivity and Growth with International Futures (IFs)

Part 1: The Productivity Formulation

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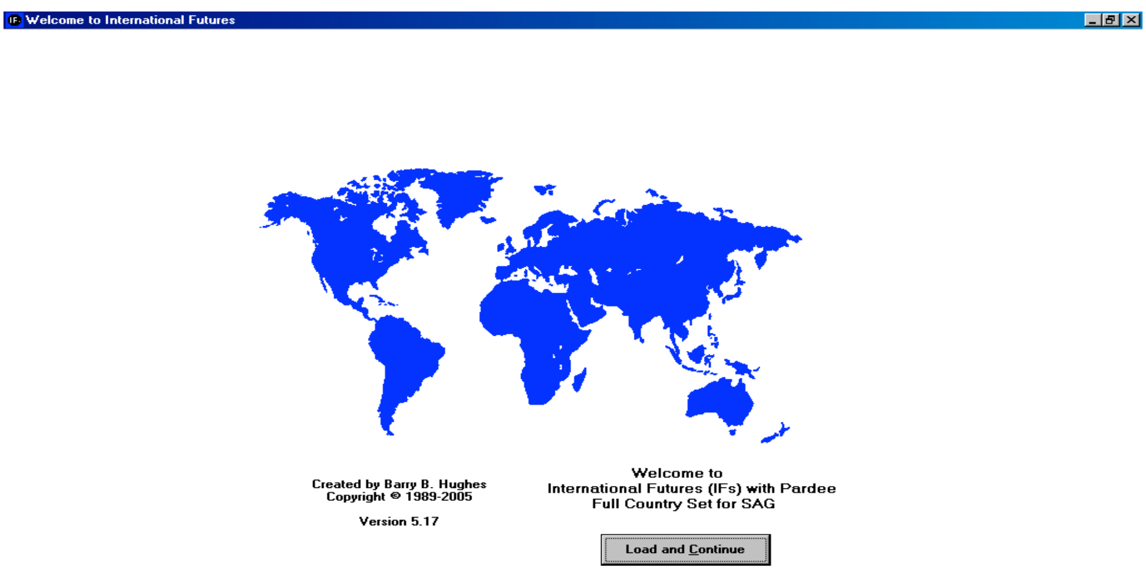
Abstract

The forecasting of economic growth is central to the forecasting of global futures. It is impossible to explore the future of human development, changes in the international political system (including power relationships) the quality of the environment, or much of anything else without looking at patterns of economic growth.

In the forecasting of economic growth, understanding the likely development of capital and labor stocks is important. Although not easy to forecast, changes in those stocks (especially labor) are easier to anticipate than multifactor productivity gains. In addition, especially for more developed countries, productivity change accounts for a higher portion of economic growth. Thus the representation of those productivity gains is a key to understanding variability of economic forecasts across countries and time periods.

This manuscript is one of two that together map an approach to representing that growth in International Futures (IFs). The first of the two (Part 1) reviews the literature around some of the key potential drivers of productivity growth, draws lessons from that literature, and describes the formulation developed within IFs to forecast productivity and growth. It also discusses the use and control of that formulation via the user interface of IFs. The second manuscript (Part 2) focuses on the drivers of productivity and, in turn, on their representation. In essence it explores what drives the drivers. That second manuscript directs special attention to a number of indices that have been developed in other literature that have proven relevant in the effort to represent productivity change within IFs.

This report is Part 1. The manuscript reviews the literature around productivity growth and maps the approach to representing that growth in International Futures (IFs).



1. The Objectives[1]

International Futures (IFs) is a large-scale integrated global modeling system. 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. The issue areas include demographics, economics, education, energy, agriculture, the environment, and socio-political systems.

Yet economic growth drives much of what happens in the other systems, including the ability to satisfy human needs, loads upon the environment, and the changing position of states in the global system. The economic model of IFs is general equilibrium, representing supply, demand, and exchange in six sectors (agriculture, energy, other primary goods, manufactures, services, and ICT). Although the demand side of the model is important, in the long-term, the supply-side and, in particular, the production function is critical. This manuscript focuses on that key aspect of IFs and documents ongoing efforts to continually improve its representation.[2]

More specifically, the major objective of this initiative within the IFs project was to undertake a significant reworking of the Cobb-Douglas style production function within IFs so as to better endogenize contemporary drivers of multifactor productivity and economic dynamism. These drivers potentially include years of education as a measure of human capital, governance quality, infrastructure extent and quality, knowledge-society orientation, and relationship of countries to the globalization process. Other papers and/or the Help system of the model discuss the full production function and the broader economic model in which it is embedded. Part 2 of the effort, a companion report to this one, documents the construction of the indices and other variables that drive the endogenous representation of productivity. This paper, Part 1 of the effort, therefore focuses quite strictly on the representation of multifactor productivity itself.

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[1] Thanks to Anwar Hossain for assistance in finding many of the indices, data, and pieces of literature that supported this project and in contributing his thoughts and advice to the work.

[2] The Strategic Assessments Group (SAG) has used the IFs system for a variety of analyses including an examination of the changing power positions of major countries. It supported this project to enhance IFs by more fully representing the drivers of change in the economic size and strength of countries. In addition, Frederick S. Pardee is providing sustaining support for the International Futures (IFs) project, and that support has helped integrate the extensions desired by SAG into a more comprehensive framework of revision in the production function of IFs.

2. Conceptual/Theoretical Design: Understanding Productivity

The most fundamental purpose of the project that gave rise to this paper was to enhance the ability of IFs to forecast dynamism and growth (or lack of it) in countries around the world, and to do so with special attention to the patterns of such growth in an era characterized by rapid technological change and globalization. Dynamism and growth ultimately determine the ability of countries to improve the human condition and determine relative positions of countries within the global system.

Untold numbers of economists and other analysts have focused on essentially the same issue. The most common focal point of their analysis is the production function used in forecasting economic growth. Evolution of that function in recent decades has been driven primarily by attempt to specify productivity advance (sometimes conceptualized as technological advance, but this project prefers to conceptualize technology as one of the drivers of productivity) with more clarity and precision.

Chen and Dahlman (2004) nicely traced part of the evolution of thinking about production functions and technology.[3] They began with Solow's (1956) formulation of a Cobb-Douglas function with a level of total factor productivity (TFP) or multi-factor productivity (MFP) dependent on time – that is, a constantly growing multiplier on capital and labor terms from growing technological prowess. Romer (1986, 1990, 1994) and Lucas (1988) began to decompose that constant term, and simultaneously to provide the basis for making it time-variable, by examining the contribution of human capital or knowledge stock. The elaboration has come to be termed endogenous growth theory and much subsequent work has occurred within it. For instance, Grossman and Helpman (1991) examined the productivity implication of importing technological know-how with the import of goods and Coe and Helpman (1995) studied the contributions of both domestic and foreign research and development (R&D). Considerable further such work will be identified later in this paper.

[3] Large numbers of other scholars have laid the foundations for and undertaken multivariate analyses of productivity. We begin this discussion with Chen and Dahlman because they focused heavily on contemporary, knowledge-society-based drivers in their recent study.

Chen and Dahlman themselves ultimately broke the drivers of TFP into four categories (2004:8). In their words:

> 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

The first term of their formulation for endogenous TFP growth gives prominence to what is commonly called governance. They elaborated it within a section on economic regime and institutional quality. For economic regime they pointed to an indicator of trade openness. With respect to institutional quality they pointed to an index of property rights protection, further elaborating the concept in terms of the International Country Risk Guide's (ICRG) attention to the rule of law, repudiation of contracts by government, and corruption in government and the quality of bureaucracy. The ICRG data have been widely used in many studies, but somewhat surprisingly, Chen and Dahlman did not look also at the World Bank's own database on governance (with work led by Daniel Kaufmann); IFs does draw on that data.

Their second term is pretty much self-explanatory, but the indicators they looked to include adult literacy rate, school enrollment ratios, and average years of schooling. They noted that the literature has turned in recent years to average years of schooling as an especially useful measure of the stock of education within a population. The education submodel within IFs provides that measure (tied to Barro and Lee data as suggested also by Chen and Dahlman) and IFs will look to such education stocks in its own productivity formulation. Interestingly, Chen and Dahlman did not consider the importance of a population's health as part of human capital; this is a factor to which Jeffrey Sachs and the Millennium Development Goals project, as well as many other analysts have devoted considerable attention.

With respect to new technology they looked to patent counts and scientific articles. Royalty payments and receipts from other countries can indicate innovation in new technology, whereas payments to others can suggest adaptation from abroad. The same is true with foreign direct investment flows. Imports of manufactured goods (especially machinery and capital goods) can also indicate adoption of technology [they note papers by Lee 1995 and Mazumdar 2001 but do not provide full citations]. Interestingly, they did not look to R&D expenditures, something we consider in IFs.

And with respect to information and communication infrastructure they looked to numbers of computers, internet users, internet hosts, phones, television sets, radios, and newspapers (all adjusted by population size). They did not consider the importance of more traditional infrastructure (roads, railroads, ports, etc), which the authors of the strategy papers for the Millennium Development Goals emphasized fairly heavily.

The work of Chen and Dahlman built upon a large literature that has analyzed productivity growth. The next chapter will explore that literature at some length. Among the strengths of Chen and Dahlman are (1) their overall framework or taxonomy of drivers of productivity and (2) their heavy emphasis on contemporary drivers.

2.1 Representing Productivity in IFs

The International Futures (IFs) project moved over several years (first documented in the model's Help system in 2002) toward a somewhat similar taxonomy of factors to facilitate endogenization of the multifactor productivity term in the production function. An important, but not exclusive theoretical foundation of the approach in IFs, as in much of the productivity literature, is the notion of conditional convergence. That is, almost all countries have the potential for catching up with global productivity/technology leadership, via what some have represented as an inverted U-shaped curve of basic convergence, with least developed countries least able to adopt existing technology and with those countries nearest the leader(s) less able by definition to benefit from adoption.

Around any crude and stylized notion of how countries might converge with a technological leader or leaders, a variety of factors influence whether countries actually do converge. Although the productivity literature tends to focus on human and social capital, the table below categorizes factors into human, social, and physical capital categories. In addition, there are activities/mechanisms, such as R&D spending along with trade and foreign direct investment, that can directly influence knowledge adaptation and creation.

- Productivity Convergence
    - Basic Pattern
- Human Capital
    - Education and Training (quantity and quality)
    - Health
- Social Capital and Governance
    - Trust/Community Strength
    - Governance Quality
    - Governance Policies/Orientation (especially openness/liberalization)
- Physical Capital
    - Infrastructure (traditional and modern)
    - Robustness of Systems (e.g. energy diversity)
    - Natural Capital (forests, land quality, etc.)
- Knowledge Base
    - Creation (especially system leader(s))
    - Adaptation/Diffusion

Such general taxonomies inevitably risk overlap and interaction of elements on the list. For instance, openness/liberalization is very much overlapping with the adaptation/diffusion of knowledge; education and training similarly overlap with knowledge creation, which is often done in association with tertiary education. Nonetheless, it is important to begin with a comprehensive framework so as to avoid important omissions, only subsequently addressing the issues of redundancy or overlap.

Before this project began, the representation in IFs of productivity already built heavily on this taxonomy with a representation of basic convergence, driven by elements of human capital (education spending, life expectancy, and health spending), of social capital (an index of economic freedom or liberalism), of physical capital (a term linking energy prices to quality of physical capital), and of knowledge base (R&D spending, growth of electronic networking, and import levels relative to the GDP).

The key objectives of the project, as stated earlier, include reformulation an extension of this representation. Specifically, the significant refinement of the education model in IFs over the last year facilitates movement from education spending (an input) to years of education in the population (an output) as a driver of productivity. The addition of a measure of governance quality, an element emphasized heavily in the productivity literature reviewed in the next chapter, enhances the formulation. So, too, does the addition of indicators of infrastructure (traditional and modern technology) and of indicators of technological dynamism and globalization that, even if not included directly in the production function, will be useful in representing dynamism of countries. And the project is allowing significant enhancement in the representation and parameterization of old and new elements in the production function.

2.2 The Broader Production Function and Theoretical Approach of IFs

Although much of the discussion and analysis of growth in this manuscript will focus on the determinants of productivity growth, it is important to re-iterate that, through a Cobb-Douglas production function, capital and labor accretion remain critical determinants of growth in both the real world and the IFs model.[4] For instance, many analyses stress the contribution of health improvements to labor force participation, not to productivity enhancement. And many factors, such as improved governance quality, can increase growth both by increasing investment and improving productivity of capital; the relative importance of the two paths is difficult to tease out and may vary by development level or even by specific country (Baldacci, Hillman, and Kojo 2003).[5] IFs incorporates also savings functions that direct funds to investment and capital formulation. It also has a basic representation of the FDI and equity flows that help determine the foreign savings contribution to domestic investment. On the labor side, IFs also has a full cohort-based population model that tracks the size of the labor force and dependent populations. It incorporates a basic representation of changing female participation rates.

Further, of course, other factors, in turn, drive the above immediate drivers of productivity enhancement. For instance, foreign aid can provide the funding to improve education, health and R&D. It can, of course, also have the perverse effects of causing currency appreciation that weakens export potential and of simply displacing local expenditures in the same beneficial categories. Domestic government expenditure and revenue balances, including direction of spending towards the above categories (or towards military or other spending) further drive our drivers. IFs does portray these elements dynamically over time, using a social accounting matrix (SAM) structure to maintain balances in inter-agent class flows, but they are not our focus here.

It should be obvious from the discussion to this point that IFs has links to, but is not rooted in neo-classical growth theory. That theory typically ties growth strongly to

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[4] The World Bank's World Development Report 98/99 (p. 19) reports on work going back to Solow that suggests that 30-40% of growth come from these other factors; some studies suggest that they determine more than half of growth, especially in developing countries.

[5] They point out that the growth of GDP per capita rises by about 1% when the ratio of gross investment to GDP rises by 10 percent (p. 20). Krugman's famous article on the myth of the Asian miracle emphasized also the importance of the investment channel as opposed to the productivity channel to growth. Nonetheless, the IMF paper concludes that, with respect to fiscal policy's impact on growth, for low income countries "the factor productivity channel is some four times more effective than the investment channel." (p. 29)

capital accumulation and therefore anticipates diminishing returns. The IFs model represents capital accumulation, but looks also to the productivity growth of new growth or endogenous growth theory (Romer 1994). Yet the typology shown in the previous sub-section suggests that IFs is also not very (pardon the juxtaposition) traditionally new growth in its orientation, because endogenous growth theory tends to look especially at "externalities, increasing returns, and learning-by-doing" (Knack 2003b: 4). More generally, human capital and knowledge growth and diffusion are, of course, fundamentally important in the new growth theory. Yet the typology above includes elements of social capital, notably governance quality and governance policies, that are less prominent in that perspective. IFs generally, not just in its representation of economics, tries to represent structures as explicitly as possible (the stocks and flows often identified with, but not limited to systems dynamics modeling) and to draw eclectically on theory and data with respect to formulations for its key flows. How this is done should become clearer throughout this manuscript and other project documentation.

2.3 Next Steps

This paper unfolds by first reviewing some of the vast literature on productivity, using the above taxonomy to help organize the review. It is important to understand that the literature is heavily oriented towards historic analysis and not towards forecasting. There is remarkably and somewhat depressingly little attention in the literature to the issues of time delays and patterns of unfolding of effects – the orientation is more of comparative statics. In fact, it is striking that the literature almost never takes explicit note of two concepts that are of fundamental importance to modelers/forecasters, namely stocks and flows.

After that review, the paper will step back and attempt to draw some general lessons from the literature that can enhance the representation of productivity within IFs. Then we will return to the issue of formulating an overall approach to productivity and growth. The approach in IFs will be described and the changes made to it during this project will be elaborated.

3. The Drivers of Productivity: Literature Review

The IFs project cannot expect to replicate or significantly extend the tremendous amount of work that many, many scholars have done on productivity. Instead, for both structure and parameterization of the model, we draw on that other work, looking in particular for empirical findings and what are often referred to as "stylized facts" (generalized insights). This section reviews and mines earlier work in two stages, first looking at studies that simultaneously consider many productivity drivers and then turning to more sharply or narrowly focused analyses.

3.1 Integrated, Multi-Driver Studies

Several sources study growth across multiple factors and many countries. They thus offer an opportunity to compare and contrast the importance of a variety of different factors in our typology. They include:

> Barro and Sala-i-Martin (originally McGraw-Hill 1995; first MIT edition 1999) *Economic Growth*
>
> Barro (1997; second MIT edition 1999), *Determinants of Economic Growth*
>
> OECD (2003), *The Sources of Economic Growth in OECD Countries*.
>
> OECD (2004). *Understanding Economic Growth*. [This document overlaps heavily in analysis and text with OECD (2003)]
>
> Chen and Dahlman (2004) "Knowledge and Development: A Cross-Sectional Approach"
>
> Jamison, Lau, and Wang (2004 revision) "Health's Contribution to Economic Growth in an Environment of Partially Endogenous Technical Progress"
>
> Baldacci, Clements, Gupta, and Cui (2004) "Social Spending, Human Capital, and Growth in Developing Countries: Implications for Achieving the MDGs"
>
> Bosworth and Collins (2003) "The Empirics of Growth: An Update"

The remainder of this chapter will present empirical findings from each of the above works.

Barro and Sala-i-Martin and Barro[6]

The two Barro books (including the first and more complete book on *Economic Growth* with Sala-i-Martin) are perhaps the "gold standard" classics of extensive, multifactor productivity studies. The first one examined a very extensive range of possible productivity drivers across the taxonomy presented in the previous chapter across 97 countries using a panel design across 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. Although the statistical base of the second study is somewhat superior, the first presents results quite a bit more extensively. This discussion summarizes empirical results from both studies.

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).

Educational Attainment

Barro and Sala-i-Martin (1999) used average years of education as the key variable:

> The estimated coefficients mean, for the 1965-75 sample, that a one-standard-deviation increase in male secondary schooling (0.68 years…) raises the growth rate by 1.1 percentage points per year, whereas a one-standard-deviation increase in male higher schooling (0.091 years) raises the growth rate by 0.5 percentage points per year. (p. 431)
>
> A puzzling finding is that the initial levels of secondary and higher education tend to enter negatively in the growth-rate equations… One possible explanation for the negative estimated coefficients is that a large spread between male and female attainment is a good measure of backwardness; hence, less female attainment – especially at the higher level – signifies more backwardness and accordingly higher growth potential through the convergence mechanism. (pp. 431-32)

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[6] Barro (1991) predates and presages these studies; although it is often cited, the more recent works provide better empirical insight. The earlier work did conclude that "poor countries tend to catch up with rich countries if the poor countries have high human capital per person (in relation to their level of per capita GDP), but not otherwise." (p. 437). Note the clear reference of human capita relative to level of development – a core feature of the approach used within IFs and elaborated in later chapters.

They noted that researchers without access to attainment data have used enrollment data in the past. They found that enrollment data have the same direction of influence as attainment data, but the results are insignificant (p. 437).

Barro (1999):

> On impact, an extra year of male upper-level schooling is therefore estimated to raise the growth rate by a substantial 1.2 percentage points per year. (In 1990, the mean of the schooling variable was 1.9 years, with a standard deviation of 1.3 years). …Male primary schooling (of persons aged twenty-five and over) has an insignificant effect… …female education at various levels is not significantly related to subsequent growth. (pp. 19-20)

Public Spending on Education

Barro and Sala-i-Martin (1999) suggested that the percentage of GDP spent on education is a “rough proxy for the quality of schooling” (p. 433):

> …a one-standard-deviation increase in *G-educ./Y* (by 1.5 percentage points for 1965-75) raises the growth rate by 0.3 percentage points per year. (p. 433)

Chen and Dahlman (2004: 18) also noted the use of spending as a proxy for quality as well as reviewing (pp. 18-20) other measures.

Life Expectancy

Barro and Sala-i-Martin (1999) used life expectancy at birth:

> …a one-standard-deviation increase in life expectancy (which is equivalent to 13 years for 1965-75) is estimated to raise the growth rate by 1.4 percentage points per year. (p. 432)

Fertility Rates

Barro and Sala-i-Martin (1999) looked not only at the affect that economic level and other variables have on fertility, but also at how national propensities to emphasize fertility and children influence economic growth. They relied on total fertility rate as the measure:

> …a one-standard-deviation increase in the fertility rate (in the 1965-75 sample) lowers the per capita growth rate by 0.7 percentage points per year. (p. 438)

Government Consumption

Barro and Sala-i-Martin (1999) used government consumption net of spending on defense and non-capital outlays for education as a portion of GDP in an analysis of the degree to which it might crowd out investment or otherwise (say as a proxy for corruption level or intervention in the economy):

> …a one-standard-deviation increase in G/Y (by 6.5 percentage points in the 1965-75 period) is associated with a fall in the growth rate by 0.7 percentage points per year. (p. 434).

Barro (1999):

> The estimated coefficient is -.136 …(p. 26). [Contrast with -.11 in Barro and Sala-i-Martin (1999)]

Political Instability

Barro and Sala-i-Martin (1999) used the average of revolutions per year and political assignations per million to measure instability:

> …a one-standard-deviation increase in political instability (a rise by 0.12 in the 1965-75 period) lowers the growth rate by 0.4 percentage points per year.

The Rule of Law Index

Barro and Sala-i-Martin (1999) looked at five measures from the International Country Risk Guide (ICRG) on the quality of political institutions (drawing on Knack and Keefer 1994) and found that the rule of law ("the extent to which institutions provide effectively for implementation of laws, adjudication of disputes, and orderly succession of power") has the most explanatory power:

> …an increase in the measure of the rule of law by one standard deviation (a rise by 2 along the scale from 0 to 6) raises the growth rate by 0.8 percent per year. (p. 440).

They noted, however, that the quality of the bureaucracy is correlated with the rule of law at the level of 0.92 (see the high correlation found in Chapter 2).

It should be noted, however, that Knack and Keefer (1995), who used data from both the ICRG and BERI political risk analysis services, focused on identifying the correlations of institutions, especially the protection of property rights, with growth via increased investment, not through the path of increased productivity growth.

Barro (1999):

> …an improvement by one rank in the underlying index (corresponding to a rise by 0.167 in the rule of law variable) is estimated to raise the growth rate on impact by 0.5 percentage point. (p. 29)

Tariff Rate

Somewhat surprisingly, Barro and Sala-i-Martin (1999) did not incorporate an overall measure of economic openness or liberalization in policies into their analysis. They did look at tariff rate, but had only a single year (1980) of data. They found a slightly negative but insignificant relationship with growth that they attribute partly to inadequate data.

State of Financial Development

Barro and Sala-i-Martin (1999) used the ratio of liquid liabilities to GDP as a proxy for financial development:

> …a one-standard-deviation increase in the liquid/liabilities ratio (by 0.26 in the 1965-75 period) raises the per capita growth rate by 0.4 percentage points per year. (p. 443).

Inflation

Barro (1999) explored the linkage between inflation and growth. He found a negative relation at levels of inflation above 20 percent, but no significant relationship at lower levels (p. 95).

Assorted Other Variables

Barro and Sala-i-Martin (1999) also considered war and defense spending in their analysis. They found no impact of defense spending as a portion of GDP on growth and an insignificant impact of war, which they attributed to poor data (p. 441).

Using Freedom House measures of civil and political liberties, they found an insignificant relationship and concluded that "If one wants to argue that democracy is good for growth, then the channel of effects has to operate indirectly from democracy to some of the independent variables, such as educational attainment and market distortions." (p. 439) Barro (1999: Chapter 2) explored this at greater length with the same conclusion, but also substantially explored the link from economics to democracy.

They examined the contribution of the ratio of investment to GDP and their analysis suggested that the relationship may run from GDP growth to investment rather than the other direction (p. 433); Barro (1999: 32-33) explored this further with the same general conclusion. Separating private and public investment data makes no significant difference (p. 442). They looked also at the black-market premium of foreign exchange, finding that "a one-standard-deviation increase in the variable … is estimated to reduce the growth rate by 0.6 percentage points per year." (p. 435). They looked further at the terms of trade and found that a one-standard-deviation increase in the growth rate of it raises growth by 0.4 percent (p. 435); Barro (1999: 30) also found it significant.

In addition they looked at regional dummies, anticipating that other variables included would largely make them unnecessary. They did find a significant negative relationship with growth for the Latin American dummy, suggesting that "adverse effects of government policies, such as corruption and market distortions" were not adequately captured by other variables (p. 444).

The analyses reported above by Barro and Sala-i-Martin (1999) and Barro (1999) will be very helpful in elaborating the formulations in IFs, particularly in the areas of human capital and some elements of governance. There are, however, significant areas of our typology of growth factors that they did not touch upon, especially knowledge development and adaptation. Fortunately, there is some help available in those areas from the OECD (2003) study of *The Sources of Economic Growth in OECD Countries* and from Chen and Dahlman (2004).

The OECD (2003 and 2004) and Productivity

In the "Summary and Policy Conclusions" the OECD (2003) authors saw contribution of ICT as having affected growth primarily in the US and Finland by "offering new investment opportunities" (2003: 16). They went on in subsection headers to say that "Looking at the key drivers of growth, investment in human, physical and knowledge capital is key… and can be encouraged by appropriate macroeconomic policies… Pro-competitive regulations improve productivity performance. (2003: 17-18). More specifically within the subsections of OECD (2003):

> Most notably, the estimated impact of increases in human capital (as measured by average years of education) on output suggests high returns to investment in education. The results also point to a marked positive effect of business-sector R&D, while the analysis could find no clear-cut relationship between public R&D activities and growth, at least in the short term. The significance of this latter result should not however be overplayed as there are important interactions between public and private R&D activities as well as difficult-to-measure benefits from public R&D …from the generation of basic knowledge that provides technology spillovers in the long run.
>
> Policy and institutions are also found to play an important role in shaping long-term economic growth. In particular, high inflation tends to dampen incentives to invest… Moreover, the uncertainty generated by highly volatile prices seems to curb economic growth… In addition, there is some support to the notion that the overall size of government in the economy may reach levels that impair growth…
>
> …pro-competitive regulations improve industry-level productivity performance by enabling a faster catch-up to best practice in countries that are far from the technological frontier… (2003: 17-18)

Chapter 2 of the study provided some more specific results from quantitative analysis of 21 OECD countries over the 1971-98 period. These included (2003: 76-78):

> The estimated coefficients for physical capital are broadly consistent with other growth studies: i.e. on average a 1 percentage point increase in the investment share brings about an increase in steady-state GDP per capita of about 1.3 per cent. The coefficients on human capital still suggest relatively high returns to education: the long-run effect on the level of GDP per capita of one additional year of education (corresponding to a rise in human capital by about 10 per cent)

> ranges between 4 and 7 per cent. These values contrast with many studies that found no or very limited effects of human capital on growth (see for example, Behhabib and Spiegel, 1994; Barro and Sala-i-Martin, 1995). As pointed out by Bassanini and Scarpetta (2001), better data quality and a more appropriate econometric procedure are likely to account for the encouraging results on human capital report in Table 2.3. It should also be stressed that the present estimates are broadly consistent with estimated returns to schooling in the microeconomic literature (see Psacharopoulos, 1994).

And latter they reported (OECD 2003: 88-89):

> - The point estimates for the variability of inflation suggests that a reduction of 1 percentage point in the standard deviation in inflation – e.g. about one-half of the reduction recorded on average in the OECD countries from the 1980s to the 1990s – could lead to a 2 per cent increase in long-run output per capita, *ceteris paribus*.
>
> - The effect of the level of inflation works mainly through investment: a reduction of one percentage point – e.g. one-quarter of that recorded in the OECD between 1980s and 1990s – could lead to an increase in output per capita of about 0.13 per cent, over and above what could emerge from any accompanying reduction in the variation of inflation.
>
> - Taxes and government expenditures seem to affect growth directly and indirectly through investment. An increase of about one percentage point in the tax pressure – e.g. slightly less than what was observed over the past two decades in the OECD sample – could be associated with a direct reduction of about 0.3 percent in output per capita. If the investment effect is taken into account, the overall reduction would be about 0.6-0.7 per cent.
>
> - A persistent 0.1 percentage point increase in R&D intensity (about 10 per cent increase with respect to average R&D intensity) would have a long-run effect of about 1.2 per cent higher output per capita under the "conservative" interpretation of the estimation results. However, in the case of R&D it is perhaps more appropriate to consider the results as reflecting a permanent effect on growth of GDP per capita (i.e. a fall in R&D intensity is unlikely to reduce the steady-state level of GDP per capita but rather reduces technical progress). If the R&D coefficient is taken to represent growth effects, a 0.1 percentage point increase in R&D could boost output per capita growth by some 0.2 per cent. These estimated effects are large, perhaps unreasonably so, but nevertheless point to significant externalities in R&D activities.
>
> - Finally, an increase in trade exposure of 10 percentage points – about the change observed over the past two decades in the OECD sample – could lead to an increase in steady-state output per capita of 4 per cent.

The OECD (2004) study reported similar conclusions to its macro analysis (in fact, the wording is the same).

Chen and Dahlman (2004) and Productivity

Chen and Dahlman (2004) also expanded their analysis of the drivers of growth well beyond human capital to include knowledge development and adaptation as well as governance. They also used an approach based conditional convergence, drawing upon data for 92 countries from 1960 through 2000. They reported their results in terms of four "pillars" of contribution to growth that Chapter 2 identified earlier.

With respect to *human capital stock/education* they found that:

> …an increase of 20 percent in the average years of schooling of a population tends to increase the average annual economic growth by 0.15 percentage point. (p. 1)
>
> …a one-year increase in the average years of schooling increases economic growth by 0.11 percentage point (p. 38)

With respect to *innovation* they found that:

> …a 20 percent increase in the annual number of USPTO patents granted is associated with an increase of 3.8 percentage points in economic growth (p. 1)
>
> …a one percent increase in the number of journal articles tends to be associated with a 0.22 percentage point increase in annual economic growth… (p. 40)
>
> …a doubling of royalty payments and receipts tends to lead to approximately 0.08 percentage point increase in the average rate of economic growth… (p. 40)

With respect to *information and communications technologies (ICT)* they found that:

> …when the ICT infrastructure, measured by the number of phones per 1000 persons, is increased by 20 percent, we find that annual economic growth tends to increase by 0.11 percentage point. (p. 1)
>
> …a 100 percent increase in the number of computers would lead to an increase in the annual economic growth rate of 0.54 percentage point (p. 41)
>
> …a 100 percent increase in the number of internet users would lead to a 0.27 percentage point increase in the annual rate of economic growth (p. 41)
>
> …a doubling of the …number of computer hosts tend to increase economic growth… by 0.13 (p. 41)

With respect to *economic and institutional regime* Chen and Dahlman (2004: 42) used "the Sachs-Warner (1995) index of economic openness and the institutional quality index from Bosworth and Collins (2003)." When those regressors are included, they found that the human capital and other knowledge variables are no longer significant. They attributed this to the high correlations of good governance with those variables and reported that other studies, including Bosworth and Collins (2003) have had the same findings.

Jamison, Lau, and Wang (2003) and Productivity

Although the title of this study suggests that it is focused only on health and economic growth, the study looks much more generally at health, education, openness, and implications of being a tropical or coastal state. The study used a "meta-production function" approach, around a Cobb-Douglas function (which seems typical in most studies), involving panel data for 53 countries over the 1965-90 period. On the whole they found affects on growth through technical progress to be a lower portion of total growth (as to affects through physical capital investments) than do many studies. Specifically, they found that "Increases in physical stocks dominate (accounting for 67% of total growth) but both education improvements (14%) and health improvements (11%) are important, and relatively much more so in some countries." … "Our findings point to the importance of investment – in physical capital, education, and health – for affecting economic outcome levels in the medium term. They point to the importance of economic openness for increasing the rates of technical progress." (p. 18).

Health

The study used survival rate of males between 15 and 60 as the measure. Although they found that the variable account for "about 11% of growth during the period," they were particularly interested in the pathway and concluded that the "effects were on income levels, not on changing the rate of technical progress." (p. ii).

Education

The study used the Barro-Lee variable of average years of schooling attained by males between 15 and 60 (p. 4). In contrast to health they found that the affect of education is "plausibly in part through technical progress, but the magnitude of that effect was small." (p. 18).

Being in the Tropics and/or Being a Coastal State

This constant condition was "estimated to result in a downward shift in income *level* of between 27% and 37%" (p. 13). They found the affect to be through income level only, not technical progress. They noted (p. 15, fn 13) that this is not substantially different from the 47% reduction in income found by Radelet, Sachs, and Lee (1997, p. 14).

In contrast, being a coastal state had its effect on growth "only through technical progress." (p. 13). They found that "other things equal, an inland Bolivia would have an annual rate of technical progress 0.9% less per annum than, say, a highly coastal Jamaica." (p. 16).

Openness to Trade

Perhaps the strongest effect they found was from trade openness, using a measure from the Harvard Center for International Development (p. 4). "The difference between fully closed and fully open trade policies is …about 1.7% per year…", substantially through technical progress (p. 16).

Baldacci, Clements, Gupta, and Cui (2004) and Productivity

This study used panel data from 120 developing countries from 1975 to 2000 in an examination of direct and indirect channels to growth from social spending (education and health), governance, budget deficits, and inflation. One of the useful features is a set of simulations with specific and targeted policy interventions.

Education

"…raising average education spending by 1 percent of developing country GDP (and maintaining it at that higher level) would increase the sum of the primary and secondary enrollment rates….and the per capita growth rate would rise by about 0.5 percentage point per year on average over the simulation period. Such an improvement in growth could reduce the initial poverty headcount by about 17 percent over a 15-year period." (p. 24).

The authors indicated, however, that the impacts on educational outcomes and growth involve considerable lags. "Two-thirds of the direct impact of education spending is felt within five years, but the full impact materializes with a significant lag of 10 to 15 years." (p. 27) "An increase in education spending of 1 percentage point of GDP is associated with 3 more years of schooling on average and a total increase in growth of 1.4 percentage points in 15 years." (p. 27). This lag effect may reinforce the utility of using an education "stock" measure such as years of education in the population of more than 15 or 25 years in age.

Health

"Raising average health spending by 1 percent of GDP would reduce the under-5 child mortality rate by 0.6 percentage point… In addition, there are also small but positive effects from health spending on school enrollment and growth. On average, the net enrollment rate in developing countries would rise by about 2 percentage points… and the growth rate would rise by a total of 0.5 percentage points over 15 years." (pp. 25-26).

"Similarly [to education], an increase in health spending of 1 percentage point of GDP is associated with an increase of 0.6 percentage points in the under-5 child survival rate and a rise of 0.5 percentage point in annual per capita GDP growth." (p. 27).

Governance

"A change in the governance index from lower- to higher-than-average is associated with an immediate reduction of 0.5 percentage point in the child mortality rate, an increase of 6 percentage points in the composite enrollment rate, and a rise of 1.6 percentage points in per capita GDP growth… The positive impact of elevating a country from a below- to higher-than-average level, therefore, is comparable to an increase in education spending of 1 percent of GDP." (p. 26) "Therefore, reducing corruption and increasing accountability for public spending are no less important than increasing spending." (p. 27). The study's measure of governance was "the sum of the simple annual averages of two indices on corruption and democratic accountability, which are two components of the ICRG rating produced by the Political Risk Service Group." (p. 31).

Inflation

"Cutting the rate of inflation by 10 percentage points (e.g., from 40 percent to 30 percent) is associated with a 0.5 percentage point increase in annual growth." (p. 26)

Fiscal Deficit

"Improving the fiscal balance by 1 percentage point of GDP is associated with an increase in per capita GDP growth by 0.5 percentage point." (p. 26). The authors noted, however, that, in contrast to social spending, such reduction does not bring additional lagged benefits and that reduction in a low-deficit environment does not have significant effects.

Bosworth and Collins (2003) and Productivity

This study looked at 84 countries over the 1960-2000 period. It made an exceptional effort to identify the sources of differences in previous studies and to compare and contrast results of them and to place its own results in the context of them. For instance, it noted the differences between studies based on growth accounts (focused on the more proximate sources of growth) and growth regressions and combined their use in this report. And it examined fairly carefully the implications of using different measures of key variables, most notably investment. It further compared and contrasted the 1960-80 and 1980-2000 period as well as examining the entire 40-year range.

Overall Division of Contributions to Productivity

For the world over the 40 years, "increases in physical capital per worker and improvements in TFP each contributed roughly 1 percent per year to growth while increased human capital added about 0.3 percent per year" (p. 7). They noted a wide range of results in other studies, some attributing about 80% of variation in income per capita to physical and human capital, with others sharply challenging the role of capital accumulation (p. 9).

Education

Much of their analysis assumed a 7 percent return to each year of education, basing that on the lower end of existing micro-analysis based studies. (p. 7) That assumption leads to an annual contribution to growth of about 0.3 percent (p. 17).

They noted that early studies (like Barro and Sala-i-Martin (1995) used initial levels of education and found significant associations with growth, while later studies used changes in years of schooling against changes in average incomes, not finding significant correlations (p. 18). They reviewed and examined alternative data sets on education and noted that Cohen and Soto (2001) and Soto (2002), using their data, found returns in the 7-10 percent rage, "close to the average of microeconomic studies. (p. 20)

They also found that a measure of educational quality helps explain growth, but at the expense of educational attainment. And they found that addition of governance quality washes out the contribution of educational quality (p. 29).

Governance

Like many other studies, they used the ICRG data of Knack and Keefer (1995) and found it to be more powerful than that of Kaufman, Kraay, and Zoido-Lobaton (2002).

Policy Choices

They examined inflation rate, government budget balance, and trade openness and the relationships with growth were in the expected direction, but only budget balance was significant. (p. 30). On the whole the relationships were not strong. "Variations in the budget balance have their primary impact on capital accumulation, presumably because budget deficits are a competing use of national saving. One surprise is that the correlation of both the trade instrument and trade openness with growth appears to operate through capital accumulation rather than TFP. Much of the theoretical literature has emphasized the efficiency gains from trade." (p. 32).

They found that trade and openness to trade became more important after 1980. In general, they found it difficult to explain the differences between the periods before and after 1980, including the sharp acceleration of growth in China and India thereafter and the downturn in growth almost everywhere else.

"…indicators of geography and predisposition to trade appear to have become more important (especially for low income countries) since 1980. There is also considerably more evidence of catch-up for the poorer countries in the later time period." (p. 38).

High versus Low Income Countries

"…we find surprisingly small differences between determinants of growth between high and low-income countries over our entire time period." (p. 35)

Conditional Convergence

"…the finding of a strong negative association between initial income and subsequent growth provides very robust support for a process of conditional convergence." (p. 37.

3.2 More Narrowly or Sharply Focused Analyses

Moving from the above, quite comprehensive and integrated studies, to those that have focused on one or a relatively small number of possible drivers of growth, means turning to a huge mass of literature. In some sense, most of economic writing is about growth.[7] Thus the literature selected for quick discussion below is partly a result of search to fill specific holes in the above discussion, partly to provide balance with respect to findings, and partly random based on the serendipity of literature discovery. Most of the studies below also consider more than a single productivity driver, because it is almost impossible to empirically study just one in a system of drivers known to be highly interactive; most, however, focus on one or a small set.

We move below through the categories of our typology of growth factors.

Human Capital

Education and Training (quantity and quality)
Health

Psacharopoulos (1991) did an extensive analysis of the returns to educational spending, differentiating private from public, general and vocational, female and male, and the normal primary, secondary and university/tertiary levels. He found (excerpted in Meier and Rauch 2005: 190-191) that the social rates of return to educational spending in developing countries was about 26% at the primary level, 18% at the secondary level, and 13% at the university level, all about the 10% return on capital he posited as generally available. He concluded that the rates of return for industrial countries were lower: about 11% at the secondary level and 8% at the university level. He also found that the return to private education was about 14% versus the 10% return for public education and that the return for female education was about 15% versus 11% for male education. Meier and Rauch note that in updates of his analysis, the latest in 2002, the conclusions do not change.

The World Bank (1993) has reinforced the greater returns to primary than to secondary education. In a comparative study of performance in selected East Asia and Latin American countries, they found that total education spending as a portion of GDP did not vary greatly, but that the Asian countries tended to allocate much more relatively to primary and secondary education, while the Latin American countries allocated relatively more to tertiary education. The authors link superior economic performance to the Asian pattern (Meier and Rauch 2005: 194-197).

Coulombe, Tremblay, and Sylvie (2004) found that a "rise of 1% in literacy scores relative to the international average is associated with an eventual 2.5% relative rise in

[7] Surprisingly, however, Barro (1996: 145) pointed out that "the revival of interest in growth theory and empirics is now about ten years old." He went on to note that one ironic result of the impact of new theories on endogenous growth was the revival of interest in the neoclassical model of conditional convergence.

labour productivity and a 1.5% rise in GDP per head (reported in *The Economist* September 9, 2004). Coulombe, Tremblay, and Sylvie (2004: 39) reported that "direct measures of human capital based on literacy scores outperform measures based on years of schooling in growth regressions of a sub-set of OECD countries." The significance of this is that other studies, including work by Barro (2001), have found, using years of schooling, that human capital contributes at earlier stages of development rather than for advanced countries. Coulombe, Tremblay, and Sylvie (2004: 39) also found that "literacy indicators for the female population systematically outperform comparable indicators of the male population in growth regressions."

Hanushek (1995) collected and summarized analysis of the returns to specific types of education spending, for instance in reducing teacher-pupil ratios, enhancing the education, increasing the experience or salary of teachers, spending on facilities, and increasing expenditure per pupil. Although the studies do not support the efficacy of reducing class sizes, they are mixed and generally positive on returns to investments on teachers, facilities, and total spending per student (see Meier and Rauch 2005: 201-205). Hanushek concludes that quality of education is critical and that the "continued expansion of low-quality schools—often thought to be a step on the path both to high access and high-quality schools—may actually be a self-defeating strategy" (p. 205).

There is a literature that is considerably more pessimistic about the impact of education on growth. Easterly (2001) and Pritchett (1999) exemplify this. Pritchett (1999:37) argued that

> The recent growth literature stressing the importance of human capital seems quaintly naïve of the basic facts in developing countries. Nearly all countries saw education attainment grow rapidly – even as many saw their economies collapse. While education expansion was at historic highs in developing countries growth [sic] in the 1980's and 1990's economic growth in large parts of the developing world fell to historic lows. The cross national data show that – on average – education contributed less to growth than expected …

Miller and Upadhyay (2002) also raised some complications for the relationship. They found that "giving the economy a greater outward orientation benefits total factor productivity in general but not necessarily for specific classes of countries … Among other variables, human capital expansion fails to have an independent positive effect on total factor productivity growth except for Europe (p. 23). "Including the interaction term can causes the effect of human capital by itself to become negative in low-income, African, and Latin American countries, while positive for high-income countries." (p. 24) "We, therefore, conclude that a large sample of countries included in a single panel may yield incorrect policy implications for any given country about the effects of outward orientation, human capital, or inflation. Using a smaller sample of countries with strong similarity of characteristics probably holds much greater promise." (p. 25).

[Need to review McMahon on education – is it at the office or with Mohammod?]

Turning primarily to health, Bloom, Canning and Sevilla (2001) undertook an analysis of the impact of health, as measured by years of life expectancy at birth, on productivity. They concluded that "a one year improvement in a population's life expectancy contributes to a 4% increase in output. (p. 5). This result is a little confused, however, by their finding in the body of the paper for a specific model that "increasing life expectancy by one year improves work force productivity and raises output by about 1 percent …" (p. 16).

One of the values of their study is that their model also included education (as measured by years of education in the adult population) and work experience (constructed as the number of years in the work force). With respect to education, "Our estimate of the coefficient on schooling translates into a social rate of return of 17.2 percent, which is somewhat higher than the average of 9.1 percent found in microeconomic studies." (p. 14). More generally, they found that the effects of health and work experience also are similar to those in the microeconomic literature: "This suggests the absence of externalities at the aggregate level and that calibration studies provide reasonable pictures of the proximate sources of economic growth." (p. 20). Interestingly, they also noted that their analysis of health only captures the effect on labor productivity, not the possible impact through life cycle savings and capital accumulation.

Weil (2004) noted the 4% result of Bloom, Canning and Sevilla (with a reference to a 2004 paper by them. He argued, however, that the aggregate regression approach is flawed and suggested constructing an estimate of health on national income, beginning with microeconomic estimates. He also moved away from life expectancy to four measures of health: average height, body mass, adult survival rate (expectancy at age 15), and age of menarche. Depending on the measure, his analysis concluded that "the fraction of cross-country variance in income exlained by variation in health range from 8% to 20% (Abstract).

Jamison, Lau, and Wang (2001) reviewed literature on the impact of AIDS on economic growth and presented some of their own results (their paper, however, was mostly focused on calculating broader economic welfare losses, not impact on growth). They reported (p. 3) some studies that have found a modest per-capita growth impact on Sub-Saharan Africa in which the loss in the numerator is "balanced by population loss from early death in the denominator." Their own analyses in other work, however, suggested that "increase in male mortality rates between 1990 and 2000 … would result in a drop of a very substantial 0.5% per annum in the growth rate of gdp per capita in Africa." (p. 3). Interestingly, they estimated also that the increases of life expectancy in Kenya and Zambia between 1965 and 1990 added 0.5% per year to per capita growth.

Social Capital and Governance

Trust/Community Strength
Governance Quality
Governance Policies/Orientation (especially openness/liberalization)

Much of the literature on the relationship between institutions/governance and growth looks back to North (1981 and 1990) and to Olson (1982) for some of the early theoretical argument that governments vary in their efficiency with respect to providing incentives for economic actors.

The Institutional Reform and the Informal Sector (IRIS) project that grew up around Olson at the University of Maryland, with funding from the U.S. Agency for International Development beginning in 1990, is one of the best places to look for studies of the relationship between social capital/governance and growth. Knack (2003) provides a strong collection of articles from the project, touching on all three of the elements of the typology listed above. That project has been at the frontiers of both theoretical and empirical work. For instance, Knack and Keefer (1995) were among the first to use the International Country Risk Guide (ICRG) values to measure governance. In doing so, they found "that a standard-deviation increase in the index (about 12 points on a 50-point scale) increases the annual rate of growth in per capita income by 1.2 percentage points on average" (Knack 2003b: 13). See also Olson 1996; Olson, Sarna, and Swamy 1998; and see IRIS's report to the United States Agency for International Development (Center for IRIS 1999) for an identification of literature associated with the center and associated scholars.

Hibbs (2001) wrote a very useful review of the literature that sought to tease out the relationship between institutions or governance and growth. In addition, Aron (2000) authored an especially good review of literature that cuts across many of the sub-elements or sub-dimensions in the literature and can help organize discussion of drivers of growth in the social capital and governance portion of our typology.

One of the very helpful elements of the Aron article was a conceptualization of measures used in the literature into five categories (see especially Table 1, pp. 107-113), placing also a wide range of data sources and studies into the categories, briefly summarized here:

> Institutional quality (including security of contract and property rights and institutional quality as measured by corruption indices, and bureaucratic efficiency, dimensions of market efficiency, and political rights)
>
> Social capital measures (including civil liberties, economic freedom, social capital measures, cultural values a la the World Values Survey, civic community, and institutional performance)

> Social characteristics (including ethnolinguistic fractionalization, ethnic tension, social development and capability,)
>
> Political characteristics (including type and duration of political regime, constitutional variables, measures of political transition)
>
> Political instability (ranging across a variety of datasets and measures of instability)

The article explored a number of methodological problems involved in linking such measures to growth, not least of which is endogeneity, the reality that institutions are not constant and their change can be caused by economic growth and well as causing it. The article identified the movement from simple cross-sectional correlations to panel studies to be an important advance.

In conclusion of the review Aron summarized "What we Know and What We Don't":

> The most recent literature suggests that the appropriate institutional variables to include in investment and growth regressions are those that capture the *performance* or *quality* of formal and informal institutions rather than merely describe the characteristics or attributes of political institutions and society or measure their political instability….
>
> The performance or quality measures for formal and informal institutions include respect for contracts, property rights, trust, and civil freedom. Evidence suggests that the quality of institutions has a robust and significant indirect relationship to growth via its effect on the volume of investment. There is also evidence, although it is weak, for a direct relationship between institutions and growth (2000: 128).

The Aron review emphasized that, although the argument that institutions/governance matter to economic growth has become imbedded in both academia and the policy world, there are considerable conceptualization, measurement and estimation difficulties frustrating its representation in forecasting formulations. In particular, it is important to understand which of dimensions sketched above one's analysis looks at.

As suggested by Aron, much literature has attended to the quality of institutions. Among the early efforts were Knack and Keefer (1995) and Olson, Sarna, and Swamy (1998). Both used governance measures from the International Country Risk Guide (ICRG). Olson, Sarna., and Swamy (1998) drew on measures of Risk of Appropriation, Quality of Bureaucracy, Corruption of the Government, and Law and Order Tradition. They concluded that "improvements on this front could raise the rate of growth of productivity by as much as 2% per annum in some countries." (Summary). They also noted, however, that the ICRG measures are subjective estimates by experts and that a perception of governance quality could be influenced by knowledge of good economic performance.

This problem continues with respect to essentially all measures of governance quality because they are all based on perceptions.

Another interesting paper is the work by Linder and Santiso (2002) looking explicitly at the predictive power of governance indicators as used by the International Country Risk Guide and Political Risk Service Group [results?]

Glaeser, La Porta, Lopez-de-Silanes, and Shleifer (2004) provided a useful service by reinforcing a distinction about different elements of governance that was made in review of the World Bank measures in Chapter 3. To repeat, that project made distinctions among three dimensions of governance:

> (1) the process by which governments are selected, monitored and replaced, (2) the capacity of the government to effectively formulate and implement sound policies, and (3) the respect of citizens and the state for the institutions that govern economic and social interactions among them (Kaufmann, Kraay and Mastruzzi 2003: 2).

Glaeser, La Porta, Lopez-de-Silanes, and Shleifer (2004) framed their analysis of the question "Do Institutions Cause Growth?" around the first dimension, that which fundamentally links to democratization or political liberalization. They argued that of three measures of institutions commonly used in the growth literature, risk of expropriation by the government, government effectiveness, and constraints on the executive (p. 4), the first two are outcome measures (falling in the second of the dimensions above) and may be high under either democratic or authoritarian governments. In their own analysis they maintained focus on the relationship of constraints on governments and economic growth, that is on essentially the first of the three dimensions. They found that

> a) human capital is a more basic source of growth than are the institutions, b) poor countries get out of poverty through good policies, often pursued by dictators, and c) subsequently improve their political institutions (Abstract)

Their analysis reinforces our own decision to put governance effectiveness (from the second dimension) into the production function rather than adding elements of the first dimension such as democratization. Subsequent discussion will elaborate the approach in IFs.

According to Shirley (2003: 1), Rodrik, Subramanian, and Trebbi (2002) did a comparative analysis of the impact of institutional quality, geography, and trade on economic growth and found that institutional quality "trumps" the other variables. She goes on to review a significant portion of the New Institutional Economics (NIE) literature. Among the important conclusions of the review was that institutional change is very difficult and slow, more so than is assumed by much of the foreign aid community—in fact, often beyond the 15-20 time horizon of a sequence of aid projects.

Moving beyond general governance quality, there is also a growing literature on governance policies or orientation, with special attention being paid in some of it to the notion of economic freedom. The availability of the economic freedom database of the Fraser Institute (Gwarney and Lawson 2004) has facilitated this analysis and that project has also contributed some analysis of the linkage to growth (Gwartney, Lawson, and Holcombe 1999; Gwartney, Holcombe, and Lawson undated).[8] The latter article examined the relationship for 94 countries from 1980-2000. Interestingly, they also added variables on education and geography.[9]

Gwartney, Holcombe, and Lawson (undated) found that economic freedom has two paths to higher growth, including increased investment and increased impact of investment levels of growth (productivity of the investment). Specifically, they found over the 20-year period "that a one-unit change in the initial EFW rating is associated with a 2.59 percentage point increase in private investment as a share of GDP." (p. 8). That translates into 18.9 percent more private investment. And "private investment was, on average, 25 percent more productive in countries with EFW ratings above the median compared to those with ratings below the median." (p. 19)

The authors also found that human capital was independently significant, and that although the contribution of tropical location was not significant, the coefficient indicated that the cost of such as location was between 1.4 and 1.6 percentage points in growth (p. 14).

Physical Capital

Infrastructure (traditional and modern)
Robustness of Systems (e.g. energy diversity)
Natural Capital (forests, land quality, etc.)

There are several aspects of physical capital beyond its accumulation in the capital terms of the production function that may affect productivity. Of those listed above, we will

[8] Berggren (2003) provided a fairly recent review of the literature around economic freedom. He indicated that a general finding links increases in the level of economic freedom to higher growth, but provided no useful estimates of the magnitude of the effect. Nor did Ayal and Karras (1998), although they did decompose elements of economic freedom and attempt to place them in descending order of positive impact on growth, perhaps giving monetary looseness a conceptual role in economic freedom that it would not always be given: "low money growth rate; small role played by government enterprises; rare negative real interest rates; small difference between the official and the black market exchange rates; large size of the trade sector; and freedom of citizens to engage in capital transactions with foreigners." (p. 9).

[9] Gwartney, Holcombe, and Lawson (undated: 1) argued that there are three traditions /theories explaining differences in economic growth: "First, the neoclassical theory of economic growth…focuses on the inputs of physical and human capital into the production process, and on technological advances…Second, the geographic/locational theory…argues that a temperate climate and ease of access to markets are critically important…Third, the institutional approach stresses the importance of creating an institutional environment that is generally supportive of markets …" The taxonomy of this manuscript does not include the second category, nor does the paper address its arguments. Geography is a constant (although disease control and air conditioning can ameliorate its effects) and this investigation is focused on drivers of changing growth. See Sachs (2001) and Gallup, Sachs, and Mellinger (1998).

focus extensively here only on infrastructure. And with respect to infrastructure, we will direct most of our attention to the modern infrastructure associated with ICT.

Given the World Bank's traditional role in supporting infrastructure development, it is not surprising that much of the analysis of its impact on growth comes from the Bank. For instance, from its *Global Monitoring Report* (World Bank 2004: 94-95):

> Measuring the elasticity of output to improvements in infrastructure quantity or quality gives a more concrete sense of the potential impact of infrastructure investment and associated policies. Depending on the sector, country (or country groups), and the period covered, the elasticity estimates range from 0.14 to 1.12, but the lower bound is not as small as it may seem. Consider the case of Latin America. In the 1990s, the elasticities estimated for that region imply that a 10 percent increase in infrastructure stocks would have enabled an increase of 1.4 to 1.6 percent in output – quite significant, since a rise of 1 percentage point in per capita income would reduce the share of people living in poverty by half a percentage point. Another recent study of Latin America estimated that lack of investment in infrastructure during the 1990s reduced long-term growth by 1 to 3 percentage points, depending on the country. This assessment suggests that infrastructure insufficiencies account for about one-third of the difference in output per worker between Latin America and East Asia.
>
> The story for Africa is similar. One of the most extensive multicountry studies suggests that if Africa had enjoyed growth rates in telecommunications and power generation infrastructure comparable to those observed in East Asia in the 1980s and 1990s, its annual growth rate would have been about 1.3 percent higher.

The same analysis explicitly noted saturation effects in infrastructure investment, with negative returns possible. In general they noted that returns are highest in early stages of development and lower for mature economies.

In a paper from the World Bank, Calderón and Servén (2004) did an empirical analysis with 121 countries through 1960-2000, using five-year averages. They developed an aggregate indicator with three components (p. 9): telecommunications (main telephone lines per 1000 workers), the power sector (electricity generating capacity), and transportation (length of road networks). They noted that most studies use aggregate indicators because the variables are so highly correlated. They also reported growth implications of the separate components and further analyze their impact individually and collectively on income distribution.

The effects they found are large:

> Let us consider a one-standard deviation increase in the aggregate index of infrastructure; this amounts to an increase of 1.3 in the global index, which represents an improvement of the aggregate infrastructure stock from 0.4 (the level exhibited by Ecuador and Colombia in the 1996-2000 period) to 1.7 (the

> level displayed by Korea and New Zealand in the same period)… other things being equal, such increase in the index of infrastructure stocks would raise the growth rate of the economy by 3 percentage points..”(pp 16-17).

The growth effects of one-standard deviation increases vary somewhat by component. For telephone lines it is between 2.6 and 3.1 percentage points; for power generation it is 1.7 percent; for road and railways it is 1.4 percent (pp. 17-18).

Using the Gini coefficient as a distribution measure, they also examined the impact of infrastructure on it and found substantial positive impact. This suggests that infrastructure development is significantly pro-poor.

[They cite what appears to be another useful study: Röller, L-H and L. Waverman. 2001. “Telecommunications Infrastructure and Economic Development: A Simultaneous Approach,” *American Economic Review* 91: 909-23.

A study by Waverman, Fuss, and Meschi (2005; discussed in *The Economist* March 12, 2005: 74) reported that “in a typical developing country, an increase of ten mobile phones per 100 people boosts GDP growth by 0.6 percentage points).”

Beyond infrastructure there is one additional issue that merits comment here. When energy prices rise, growth historically slows. *The Economist* (April 30, 2005: A Survey of Oil, p. 4) reported that the conventional wisdom is that a $10/barrel rise lowers global GDP growth by about 0.5%. Part of this effect is presumably because of the shorter-term, tax-like effects associated with diverting spending of consumers and producers away from savings and investment. Part of it, however, could well be associated with making some portion of the physical capital stock inefficient and uncompetitive. Both effects could slow growth over a longer period. In the face of the oil price rises of 2005, however, there was also speculation that greater energy efficiency of systems relative to the 1970s would dampen the economic impact of the rises.

Knowledge Base

Creation

Adaptation/Diffusion

The differentiation between creation and adaptation/diffusion of knowledge is not as easy to maintain in analysis as it is conceptually. R&D is sometimes portrayed primarily as an engine of knowledge creation, but the reality, as the development portion of the expression indicates, is that it very often is a driver of knowledge diffusion. Similarly trade and foreign direct investment are frequently portrayed as carriers of existing knowledge. Greenfield investments can, however, also advance the state of the art. We make no effort here to maintain a strong distinction between creation and diffusion.

Beginning with attention to R&D, Chen and Dahlman (2004: 10) reported that

> Lederman and Maloney (2003), using regressions with data panels of five-year averages between 1975 to 2000 over 53 countries, finds that a one-percentage

> point increase in the ratio of total R&D expenditure to GDP increases the growth rate of GDP by 0.78 percentage points. Guellec and van Pottelsberghe (2001) investigated the long-term effects of various types of R&D on multifactor productivity growth using panel data for the OECD over the period 1980-98. They find that business, public, and foreign R&D all have statistically significant positive effects on productivity growth.

Temple (1999) reviewed a huge literature on economic growth, looking for generalizations about factors underlying it. He pointed out the microeconomic evidence for a very large contribution of R&D to growth: in the United States during the 1950s and 1960s the private rates of return to R&D were put as high as 30-50%. There is also strong evidence for positive social or public externalities from private expenditures, explored in literature that Temple (1999: 140) cited, including Griliches (1979, 1992), Jones and Williams (1997), and Jones (1995a, 1995b). Temple concluded (1999: 152) that more study in the literature was needed here and that "The social returns to R&D are high, and even if the long-run growth rate is independent of research efforts, the welfare effects of changes in R&D expenditures can be large."

It is not surprising that total R&D investment increased in the U.S. at a real annual rate of 6 percent between 1994 and 1999, compared to 0.3% between 1989 and 1994. In 1998 the Department of Commerce determined that IT-focused R&D was 32% of the total (US DOC: 31). For 1997 the OECD (2000b, 34) measured ICT R&D to be 35% of total business R&D across the OECD, 24% in the European Union, and 38% in the United States. Thus the emergence of the New Economy may be accompanied by higher levels of R&D expenditure and a focus on ICT, with a positive feedback to growth.

There may, however, be still another R&D-related impact of the New Economy, tied to the efficiency of R&D expenditure, not just the level of it. The connections within and across research communities, and the connections of those communities to information sources and computing capability are, as nearly all researchers are experiencing, of phenomenal importance to the efficiency of research itself and even to the ability to undertake certain kinds of research. The massive effort within genetics, focused first on mapping genes and then on understanding and manipulating them, is one critical example and an illustration of the kind of large-scale technological change that Gordon discussed early in the century. Hal Varian (2000) wrote of innovations that spur "recombinant growth," because they can be broken into multiple parts that lead to new inventions. It might be more accurate to characterize ICT as a "meta-innovation" that may facilitate a vast number of other innovations.

Suffused with network-like effects, an economy could even exhibit *increasing returns to scale* of investment and economic activity, rather than the negative or constant returns of more traditional economics. It would be appropriate, however, to close this section with a reminder before we turn in the next to ICT. The productivity impact of the so-called New Economy has only really appeared clearly in the statistics of the United States, and even that may not survive the collapse of ICT-related equity markets. Soete and ter Weel

(2001), in a cautiously optimistic paper, reminded us of the many failed one-time forecasts of transforming technologies, including nuclear energy.

Globerman (2000) reviewed empirical work on the private and social returns to R&D spending and found them to be in the 30-40% range; see also Griffith, Redding, and Van Reenen (2000).

Abdih and Joutz (2005: 4-5) investigated the knowledge production function in considerable detail for the United States, focusing on patent numbers as a measure for knowledge. They concluded that "the long-run impact of the knowledge (patent) stocks on TFP is small; doubling the stock of knowledge (patents) is estimated to increase TFP by only 10 percent in the long run….the rate of diffusion of new knowledge into the productive sector of the U.S. economy has been slow over the pat 20 years."

Lim (2001) reviewed the literature on the impact of FDI on growth and also on the determinants of FDI. He noted that the consensus of the literature is that FDI does boost growth through improvements in technology and management practices, but "there is no strong consensus on the associated magnitudes" (p. 4). He also noted a recurring theme in the literature that the benefits accrue after a host economy has reached a threshold level with respect to human capital and therefore absorptive capacity for technology (p. 9). The path of impact on growth can also be via "crowding in" and therefore raising total investment. Lim provided no empirical estimates of the affects of FDI on growth.

3.3 Conclusion

This chapter is grist for the mill. The studies are too different and results are too mixed to be simply incorporated into a forecasting model. Chapter 5 will return to the processing of the grist. The next chapter takes time out, however, to review some of the debate and insight around the relationships between information and communications technology (ICT) and productivity.

4. Information and Communications Technology (ICT)

In addition to the literature that focuses specifically on infrastructure, including that for information and communications technology (ICT) and beyond the literature looking at R&D and its two-way connections to ICT, there is a broader literature on the linkages between ICT and productivity that is of interest to us here. Much of it has emphasized the United States because it was there, in the last years of the 1990s, that the so-called New Economy, based on the productivity impetus of ICT, seemed for some analysts to be emerging.[10]

This chapter reviews some of the literature in this area. Unlike the previous chapter, which focused on specific drivers of multifactor productivity, this chapter should be read as a more general discussion of a syndrome of economic changes, some of which obviously relate to specific drivers such as education levels, ICT infrastructure, and knowledge creation and diffusion, but which more broadly defines the possibility of a shift in the rate of productivity growth. This chapter was originally prepared for the TERRA project sponsored by the European Commission and has not been fully updated.

From 1913 to 1972, nonfarm multifactor productivity (MFP) grew in the U.S. at an average of 1.6% per year; from 1972 to 1996 the rate was 0.62% (Gordon, 2000: 53). A large literature attempts to explain the downturn, but that is not our interest here. Productivity increases accelerated sharply in the late 1990s. Annual total factor productivity (TFP) growth averaged 0.34% during 1973-95, but jumped to 0.99% during 1995-98 (Jorgenson and Stiroh 2000: 127). Oliner and Sichel (2000) similarly showed about a doubling of growth in MFP in 1996-99.

4.1 Decomposing U.S. productivity.

U.S. economic growth increased by nearly 2% in 1995-98 relative to 1990-95, climbing to an annual rate of 4.7%. Much of that growth is attributable to increases in hours worked and to an investment boom (capital deepening). Of the 4.7% total economic growth rate, 2.36% came from labor hours, 0.253% from labor quality, 1.13% from capital deepening, and 0.99% from total factor productivity (Jorgenson and Stiroh 2000: 151).

Over the 1980-96 period Shreyer (2000) found that ICT capital contributed about 0.1-0.4% to annual growth, a relatively stable rate. Extending the analysis beyond 1996, Jorgenson and Stiroh (2000: 126-127) estimated that computer inputs contributed only 0.1% to growth in 1959-73, but 0.46% in the late 1990s, with software and communications equipment contributing another 0.3% for 1995-98. The estimates of productivity growth declined somewhat and estimates of ICT contributions increased

[10] This sub-section was originally drafted for the TERRA project, sponsored by the European Commission.

when Jorgenson and Stiroh (2000: 156) increased assumptions about price declines in software and telecommunications equipment.

Decomposing paths of ICT impact on productivity. Shreyer (2000) discussed the debate that drew on the work by Jorgenson and Stiroh (2000), Oliner and Sichel (2000) and others concerning the rough doubling of growth in U.S. MFP in 1996-99. One facet of the debate concerned whether the phenomenon was mostly within the ICT-producing sector or more broadly in ICT-using sectors. But even Gordon's earlier, pessimistic conclusion that gains were *only* in the ICT sector shifted; he subsequently recognized a somewhat broader pattern after his re-analysis using the revised October, 1999, U.S. National Income and Product Accounts.

Oliner and Sichel (2000) found that "the *use* of information technology and the *production* of computers accounted for about two-thirds of the 1 percentage point step-up in [labor] productivity growth between the first and second halves of the decade." About half of that came from "the growing use of information technology capital throughout the nonfarm business sector" (Oliner and Sichel 2000: 17). They attributed about another ¼ percent to the "rapidly improving technology for producing computers" (including the production of semiconductors, as significant portion of it). They noted that Gordon in 1999 attributed 0.7% to acceleration of cyclical factors or price measurement and only 0.3% to true pick-up in productivity, but that in 2000 he used revised NIPA data and found a true 0.7% increase in productivity after 1995; Gordon still, however, attributed increase to "capital deepening, changes in labor quality, and computer-sector MFP growth," rather than to IT use.

Let's look more closely at the paths to productivity increase. It is not longer true, as Solow famously said in 1987 (Solow 1987) that "You can see the computer age everywhere except in the productivity statistics." It remains true, however, that our understanding of the contribution of the computer age to productivity is muddy.

ICT Production and Productivity Increases Within the Sector.

We have already noted that, in spite of the relatively small size of the IT sector, it contributed about 30% of total U.S. growth between 1995 and 1999 (US DOC, 2000: 24).[11] No one questions that productivity growth within that sector was very high.

Jorgenson and Stiroh (2000: 128) noted an acceleration in the late 1990s in the reduction in computer prices (largely because of more rapid decline in the prices of semiconductors), from 15% per year in 1990-95 to 28% per year in 1995-98. Prices of computer software only began to fall in the late 1980s (2000: 134). Software prices officially fell 2.2% annually from 1995-98 and telecommunications equipment fell 1.7%

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[11] Jorgenson and Stiroh (2000: 172-176) note that computer equipment (SIC 357) is included in industrial machinery and equipment (SIC 35) and that semiconductors (SIC 3674) are included in electronic and electric equipment (SIC 36). In the U.S. the two more highly aggregated sectors grew at rates of 4.79% and 5.46%, respectively, across the 1958-96 period. Communications (SIC 48) grew at 5%.

annually (2000: 149). Jorgenson and Stiroh (2000: 153-155) noted that standard statistics do not, however, adequately treat quality improvements and thus price reductions in software and telecommunications equipment; in a "moderate scenario" they estimated price reductions in software at 10.1% (compare with 2.2%, above) and in telecommunications equipment at 10.7% from 1959-98.

Jorgenson and Stiroh (2000: 159) concluded in their base case that somewhat more than ½ of productivity increases attributable to IT were outside of the IT sector itself. But in their scenario of moderate declines in the prices of software and telecommunications equipment they concluded that the portion outside of the IT sector is somewhat less than 1/3.[12]

Jorgenson and Stiroh (2000: 173-175) used a Domar weight decomposition to assess the productivity by economic sector for 1958-96 across 37 sectors, roughly the 2-digit SIC categories. They found that productivity growth had been fastest, at 1.98%, in electronic and electrical equipment, the sector including semiconductors and therefore subject to Moore's Law. The second highest productivity, at 1.46%, was in industrial machinery and equipment, which includes computer production. (Interestingly, the third and fourth sectors were textile mill products and agriculture, at 1.23% and 1.17%, respectively.) Contribution to total economic productivity gains depends on the productivity rate times the sector size. Because of that, the trade sector, with a productivity rate just under 1%, contributed about four times as much to total productivity growth across the period as did electronic and electric equipment.

Outside of the ITC sector itself, much of the productivity growth must be attributed to the use of ITC in investment rather than as intermediate goods. We turn to that productivity path.

Use of ICT by Other Sectors

Traditional economic models tied economic growth very heavily to the increase of capital stock. Increased emphasis on multifactor productivity, on that portion of growth that increases in capital and labor inputs fail to explain, has broadened attention. But it has appropriately not fully shifted attention away from capital, either human or physical. It is important to consider ICT as an increasingly large investment throughout the economy and to explore whether that investment, as either a replacement for or supplement to more traditional capital, has enhanced growth.

In current dollars, business investment in IT equipment and software rose in the U.S. from 44% to 46% of all equipment spending from 1992 to 1999 (US DOC, 2000: 28). In real terms it grew considerably more rapidly, reaching more than ¾ of total business investment in equipment and software in 1999. Although in nominal terms, software

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[12] If ICT is defined as its own aggregated sector, including all elements of computer and communications hardware, software, and services, it is obvious, of course, that much of the sectoral use of ICT production will be in the ICT sector, itself (as of semiconductors to produce computers).

grew most rapidly in that investment, in real terms the primary growth was in investment in computers.

Schreyer (2000: 10) found, using IDC 1998 data, that ICT capital investment had been progressing in the G-7 at about 20% per year that that IT equipment was about 10% of total annual non-residential gross capital formation (or 20% of total durable equipment expenditure) and that communication equipment is another 5-10% of total non-residential investment.

Computers and related investment also have a very short life time in active use, however, so their growth in capital stock is not as fast as their growth in investment flow.[13] Schreyer (2000: 12) provided estimates of the share of ICT in the nominal productive capital stock of all G-7 countries in 1985 and 1996. In general the share grew about 1.5% in each country reaching early in the century a high of 7.4% in the U.S. (compared to 6.2% in 1985) and a low of 2.1% in Italy (compared to 1.3% in 1985). Of course, these percentages preceded the acceleration of ICT investment share in the late 1990s.

It is possible that ICT capital is simply replacing other capital without generating additional productivity (that seems to have been largely true through first half of the 1990s). It is also possible that ICT investment has coincided with higher investment rates (capital deepening) so that more rapid economic growth is attributable simply to additional capital and not to productivity increases. That appears partly true in the late 1990s. What we really want to know, of course, is how much ICT capital might be boosting productivity (MFP).

Measuring prices and price declines complicates knowing the true size of investment in ICT and its productivity impact (just as such measurement complicates understanding the size of the sector itself). For instance, official statistics show price declines in packaged software but not software that businesses develop internally, which is instead valued under assumptions of no productivity growth for computer programmers (Jorgenson and Stiroh 2000: 140).[14] Further, our data on investment by destination sector lags significantly.[15]

Given the measurement and conceptual complications, what can we say about the impact of ICT investment on the productivity of sectors throughout the economy? Some sectors

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[13] Jorgenson and Stiroh (2000: 135) distinguish between capital stock and capital services. The difference is the quality of capital, analogous to the way in which labor quality helps us distinguish between labor hours and labor input (the quality of U.S. labor decreased in the late 1990s while the quality of capital increased).

[14] It is important also to note that until recently the U.S. Bureau of Economic Analysis (BEA) classified software as a business expenditure or intermediate input, but has now reclassified it as a form of investment (US DOC 2000: 67). Historically, only tangibles were considered as investment and capital goods.

[15] Triplettt (1999: 4) pointed out that the 1992 U.S. data only became available in the late 1990s (it showed that more than 40% of computer investment was going to four sectors: financial services, wholesale trade, miscellaneous equipment renting and leasing, and business services).

that have invested heavily in IT, including finance, insurance, and real estate (FIRE), demonstrated negative productivity across the period. Such findings must, however, be partially suspect. The output of service sectors is often measured in terms of labor input, thereby *assuming* no productivity growth. When the U.S. Bureau of Economic Analysis switched to measuring bank industry output in terms of transactions rather than labor input, the sector began to show significant productivity gains (US DOC 2000: 68).

Consider also that employment in the banking industry of the U.S. declined by 100,000 between 1990 and 1998 (www.nsf.gov/sbe/srs/seind98/access/c8/c8s2.htm, p. 3 of 13). Similarly, the share of the GDP accounted for by other service sectors not in the knowledge economy, notably wholesale and retail trade, actually declined from 1959 to 1994 (p 2 of 13). Although the total U.S. service sector grew from 49 to 62% of the economy from 1959 to 1994, most of that growth was in knowledge-based sectors such as finance, insurance, and real estate (FIRE) and professional services like health and education. In light of such transformations, it seems improbable that many types of services were not subject to productivity gains; in fact, it seems quite possible that the long downturn in measured productivity of the U.S. economy (early 1970s to mid 1990s) was exacerbated by problems in the measurement of service productivity. Nonetheless, while Triplett (1999) acknowledged measurement problems, he urged caution in assuming too much unmeasured productivity gain.

US DOC (2000) provided a general summary of some of the above economic analysis of productivity. The authors suggested in a summary table (2000: 38) that the IT share of the overall acceleration of productivity in the late 1990s ranged from 48-74%, depending on the study. Decomposing that share, they concluded that IT own-sector production made a significant contribution, and that IT contributions to other sectors were generally positive, but mixed and uncertain.

Transformational Impact of ICT

It is important to make clear the significance of the debate that infuses the studies about relative contributions of productivity of production within the ICT sector and productivity of ICT use across the economy. We know that we have become dramatically more productive in *producing ICT* goods. We have reason to believe, but less evidence, that as ICT capital becomes a larger share of total capital stock and as the human ability to *use ICT* becomes a larger share of human capital, productivity in other sectors will also rise, because doing what we largely already do will become more efficient. Such productivity increases would probably be one-time effects spread over several years.

But is there a possibility that ICT will not just enhance what we largely do now, but significantly *transform* what we do? Might it accelerate broader technological change? If so, new configurations of physical and human capital around ICT could give rise to a long-term upward shift in multifactor productivity.

4.2 ICT Pessimism and Optimism

ICT Pessimism. Robert Gordon (2000) argued that U.S. productivity has been subject to one "big wave" over the last 100+ years, with low productivity in the 1870-1913 period, a significant acceleration between 1913 and 1972 with a peak in the 1928-50 period, and productivity rates between 1972-96 like those of 1870-1913.[16] He attributed (2000: 35-36) the crest of the wave primarily to a confluence of four sets of technological innovations: electricity, the internal combustion engine, molecular chemistry (petrochemicals, plastics, pharmaceuticals), and entertainment/communications/information innovations.

He argued "that the current information-technology revolution does not compare in its quantitative importance for MFP with the concurrence of many great inventions in the late nineteenth and early twentieth century that created the modern world as we know it" (2000: 35). He argued further that "The newest aspect of the computer revolution, the internet, can be viewed largely as a source of information and entertainment that substitutes for other forms of information and entertainment" (2000: 39).[17]

ICT Optimism. If Gordon's conclusions about the impact on MFP of the ICT revolution are to be proven wrong, it will require that the revolution be much more extensive, pervasive and transforming than it has been to date. The ICT-revolution optimists often argue that it is the development of the internet that will transform the global economy.

The optimists generally begin by noting both the growth of the internet and the power of the network effect. In 1994 three million people used the internet (US DOC 2000: iv); in early 2001 NUA estimated that number to be 407 million (www.nua.ie), of whom 167 million are in Canada and the U.S. and 113 million are in Europe. The 2001 IDC/World Times Information Society Index (ISI) identified Sweden as the world's foremost information economy, taking into account computer infrastructure, information infrastructure, internet infrastructure, and social infrastructure (www.nua.ie). About 56% of the Swedish population is connected to the internet. Those connected to the internet can access more than 1 billion pages (US DOC 2000: iv).

The growth of the internet and its impact is driven by the convergence of several technologies (US DOC 2000: 2). As Moore's Law (first noted in 1965) predicted, the number of transistors per microprocessor chip has doubled roughly every 18-24 months since the 1960s. In addition, the storage capacity of hard disks has been doubling every

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[16] It is interesting that his peak period of growth in multifactor productivity includes the great depression, an episode that typically separates long waves for most analysts.

[17] Although his conclusions are pessimistic about productivity growth in the near and mid-term future, he ironically does leave one window open for greater optimism by positing a second possible contribution to the earlier surge in productivity via a very different path. If, as he suggests, restriction of immigration (and even market openness) by the U.S. during the interwar period led to innovation of labor-saving technology, the great ongoing reductions in fertility throughout the world could be setting the stage for a similar pressure.

nine months, leading to decline in the price per megabyte of storage from $11.54 in 1988 to $.02 in 1999. Also, the carrying capacity of fiber is doubling every 12 months. Experts in these industries believe that rapid product innovation and price decline can continue for at least another decade (US DOC 2000: 61).

As individuals and organizations take advantage of the communications and information access that these trends provide via the internet, they join the users of the internet and collectively create "network effects" or "network externalities." Metcalfe's Law provides a useful entre into these effects (Shapiro and Varian 1998). It points out that the number of possible connections of two individuals on the internet grows approximately with the square of those with access.[18]

It is important not only to note the potential of such connection profusion, but to explore the elements by which that might enhance productivity or otherwise change economics and the broader society.

Even after the collapse of the dot.com stock market bubble of 2000, the potential of e-commerce is obvious. Much of the collapse was of ill-founded business-to-consumer (B2C) ventures. Forrester Associates estimated the volume of B2C transactions in the U.S. at $33 billion in 2000, approximately 1% of retail sales (www.nua.ie/surveys/analysis/graphs_charts/comparisons/ecommerce_us.html). They forecast continued growth to $108 billion by 2003. Datamonitor estimated consumer spending at European sites to be $2 billion in 2000 and forecast growth to $5 billion in 2002. [need to update this]

It is, however, business-to-business (B2B) transactions that are even more certain to grow, as increasing numbers of businesses manage their purchasing and sales via the internet. General Motors and Ford followed announcements in 1999 that they would put purchasing on line with an announcement in 2000 that they would jointly cooperate with DaimlerChrysler to create an online marketplace (US DOC 2000: 16). Forrester Associates estimated US B2B e-commerce at $251 billion in 2000, with growth to 2003 forecast at $1,331 billion.

Oliner and Sichel (2000: 21) discussed how much of such e-commerce might represent gains in efficiency and therefore contribution to MFP. Drawing on another study they concluded that 10% is a reasonable estimate. Litan and Rivlin (2000) reviewed a variety of studies that suggest that many businesses might be subject to 5-10% productivity gains as the benefits of the internet are phased in (spread out over several years). See also the *Economist* (April 1, 2000: 65). How much might such efficiency gains add to economic growth? Answering that requires that we multiply the efficiency gains by the size of the activity. The analysis by Olineer and Sichel of e-commerce volumes in 1999 suggested gains would be 0.2% of U.S. GDP, a total efficiency gain that would achieved over several years. The above numbers from Forrester Associates for e-commerce volume in 2000 would suggest a gain of about 0.35%.

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[18] More precisely, the number of connections with n users is n*(n-1).

Another positive impact of e-commerce and improved information handling could be decreased inventories. In 2000 U.S. manufacturing inventories were 12% of annual shipments versus 16.3% in 1988; even after a prolonged economic expansion, inventories in 2000 were as low as at any point in the entire 1982-90 expansion (US DOC 2000: 63). It has been suggested that this inventory reduction and other characteristics of the New Economy could dampen business cycles as well as improving efficiencies. But Robert Solow said that he would feel considerably more comfortable assessing the productivity implications of the New Economy after it has survived its first recession; in early 2001 labor productivity in the U.S. had already dropped a full point in the face of the dot.com collapse (*The Economist*, February 10, 2001: 22).

One-time efficiency gains in transaction costs and levels of inventories maintained might, however, be only part of ongoing efficiency gains in business processes as a result of widespread use of IT, including the internet. Among the ways in which such processes might change are (US DOC 2000: 19-20): coordination of product design, improving human resource functions, managing inventory control more efficiently, providing training, providing customer services and answers to frequent questions, reducing project administration and management costs. Interestingly, analysis at the firm level suggests that IT investment requires organizational/process change and decentralization of organization to deliver productivity increases (US DOC 2000: 41-42).

The debate on ICT's contribution to productivity is far from over. What are its implications for modeling and forecasting of economic growth? The IFs project has taken at least two from it. First, it is important to break out the ICT sector from other sectors in order to separate own-sector effects from cross-sector effects. Thus, for instance, in longer-term forecasting, as demand for the products of the sector saturates and the sector itself matures, the contribution of here-to-now extremely rapid own-sector productivity gains to total productivity growth will weaken. IFs added ICT as a sector in 2002. Second, the contribution of ICT and networking to other sectors are not sufficiently well understood so as to justify forecasts that do not provide users of the model with parametric control over that linkage. The IFs interface (as described later) does provide such control.

5. Drawing Conclusions from the Productivity Literature

There are several conclusions to be taken from this literature review forward to the refinement/extension of the productivity formulation in IFs. We should consider both the weaknesses and the strengths of that literature.

First, and on the weakness side, the literature does not well distinguish between stocks and flows; more generally it does not well treat dynamics. Most of the literature is regression-based and treatment of time is via a mechanical use of panels, often 5 or 10-years. That helps establish direction of impact, but does not help determine the extent of time lag or the pattern of its unfolding. There is a substantial difference between econometric analyses using regression and structural formulations representing the dynamics of change in population and education (by cohort), the accumulation and depreciation of capital stocks as a result of investment, and the similarly time-dependent unfolding of various drivers of productivity. IFs uses a structural approach, which is important for long-term forecasting both because it makes dynamics explicit and because it explicitly accounts for stocks and flows and the constraints upon flows. It is a challenge to take the results of the above literature into a long-term, structural forecasting model.

Second, it appears almost certain from the above literature that there are many complementarities across drivers of productivity. There is no silver bullet. Instead, as countries develop many of the drivers of productivity must move together somewhat in tandem. The approach in IFs builds on an assumption of complementaries.

Third, there are tremendous complexities and uncertainties in the drivers of growth. Neither structural representations nor parameterization of formulations for forecasting it can be considered settled and free of controversy. It will be important to maintain as much flexibility in formulations and parameterization as possible and to make that flexibility available to those using the software for analysis and alternative forecasts.

The rest of this chapter will attempt to draw some more specific, but fundamentally stylized facts from the literature. It unabashedly mines the above literature for generalizations.

5.1 Human Capital – Education

Some of the most clearly stated results from the studies are:

- 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. That 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 population and education submodels of IFs make 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.

5.2 Human Capital - Health

Extracting again from the studies reviewed in previous chapters:

- 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 either 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 this 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, there is reason to use years of life expectancy as the key driver. As with years of average income, life expectancy is more of a stock than flow variable. Although by addressing human illness, health spending might quickly affect productivity, there is little reason to think that most of either education or health spending should instantaneously increase economic productivity and growth. Human capital builds slowly in response to spending on 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 may have value to make available for model users the driver linkage from health spending. If that is used, it appears that an additional 1% of GDP might raise economic growth by as much as 0.5%, about the same order of effect as for education.

5.3 Social Capital and Governance – Governance Quality

Extracting from the literature reviewed:

Barro and Sala-i-Martin (1999: 440) found that, using the International Country Risk Guide (ICRG) scale for rule of law, an increase by one standard deviation raised growth rate by 0.8% per year.

Knack and Keefer (1995) used the ICRG data and found that a one standard deviation increase raised growth by 1.2% per year (reported by Knack 2003b: 13). Knack and Keefer (1995) and many other analysts direct attention to the relationship between governance and investment rates rather than productivity.

Baldacci, Clements, Gupta, and Cui (2004: 31), also using the ICRG data, found that moving the governance index from lower than average to higher than average leads to a rise of 1.6% in growth per capita, which they reported was comparable to raising spending on education by 1% of GDP (although they separately report that increasing spending by 1% raised growth by 0.5%, only one-third the impact of the governance quality change; see page 24).

Olson, Sarna and Swamy (1998: Summary) reported that improvements of governance, again tapped by ICRG measures, could raise productivity by as much as 2% per year.

Possible conclusions and stylized facts for the IFs project are:

First, the impact on growth rates of improvements in governance by one standard deviation are potentially very large, probably on the order of 1% per year.

Second, some if not most of that impact should probably be channelled to increases in investment rates than to multifactor productivity.

5.4 Social Capital and Governance – Governance Policies/Orientation

Extracting from the literature reviewed:

Barro and Sala-i-Martin (1999: 439) and Barro (1999: chapter 2) concluded that levels of democracy, as measured by the Freedom House scales, had no clear independent linkage to economic growth. There may well, however, be paths via other variables such as educational attainment and distortions of market, that link democracy to growth.

Gwartney, Holcombe, and Lawson (undated: 8) found that a 1 unit change in the 10-point Fraser Institute's economic freedom index was associated with a rise of private investment as a share of GDP by 2.59%, a rise of private investment by nearly 19%. They also found (p. 19) that private investment was 25% more productive in countries with economic freedom ratings above the median, relative to countries with values below the median.

Possible conclusions and stylized facts for the IFs project are:

First, in this area as with governance quality, the paths to economic growth appear to run both through increased investment and increased productivity, with some real uncertainty around the mix. Because of this and because of the manner in which results are reported, it is more difficult to extract stylized facts than it was for human capital

Second, there appears little reason to add a linkage between democracy level and productivity.

Third, the relationship of generalized economic freedom to growth is strong enough to suggest that a one point rise on the Fraser Institute scale could be associated very roughly with a 0.1-0.2% rise in economic growth. (If growth averages about 3.5% across countries and time, the contribution of capital to growth is about 1/3, and the increase in efficiency of capital is 25%, then moving from below the median to above would give rise to about 0.3% extra annual growth; according to IFs calculations, a standard deviation on the freedom scale, controlled by GDP per capita, is about 2.66 points; thus if we associate movement from below the medium to above it with a single standard deviation, a single point gives us the value range indicated.)

5.5 Physical Capital – Infrastructure and Energy

Extracting from the literature reviewed:

The World Bank (2004: 94-95) found that a 10% increase in infrastructure stocks would have led to a 1.4-1.6% rise in output in Latin America. In Africa, had rates of growth in infrastructure for telecom and power generation in the 1980s and 1990s been the same as those in East Asia, annual growth would have increased by 1.3%.

Calderón and Servén (2004: 16-17) found that an increase in infrastructure by 1 standard deviation would give rise to as much as 3% faster economic growth. They found (17-18) that the return is larger for telephones (2.6-3.1%) than for power generation (1.7%) or roads and railways (1.4%).

A stylized fact in wide use is that a $10 increase in energy prices per barrel shaves about 0.5% from global growth, but that the impact has been decreasing.

Possible conclusions and stylized facts for the IFs project are:

First, it will be useful to have indices of infrastructure as drivers for productivity and, in fact, to have separate indices for different components of infrastructure.

Second, it appears that an increase in aggregate infrastructure index levels by 1 standard deviation could increase growth by as much as 3%. In comparison with other drivers, however, including human capital and governance, this number seems extraordinarily high and base values in IFs should probably be lower.

Third, the impact of energy prices on growth should be treated conservatively.

5.6 Knowledge Base - Adaptation/Diffusion and Creation

Extracting from the literature reviewed:

The OECD (2003: 88-89) found that a rise in R&D as a portion of GDP by 0.1% (about 10% relative to the base), would conservatively raise output per capita by 1.2%. They conclude that the impact of the increase on growth rate would be about 0.2%. They found that business-sector R&D had a clear effect, but that public sector R&D did not, at least in the short-run; however, they inveigh against overplaying this result.

Chen and Dahlman (2004: 10) credit Lederman and Maloney (2003) with finding that a 1% increase in R&D share of GDP gives rise to an increase in GDP growth by 0.78%. They also cite Guellec and van Pottelsberghe (2001) as finding that business, public, and foreign R&D all significantly affect productivity.

Abdih and Joutz (2005: 4-5) argue that the rate of diffusion of knowledge into productivity is very slow and provide estimates of ultimate impact that are considerably more conservative than those above.

The OECD (2003: 88-89) found that a rise in trade as a portion of GDP by 10% raised steady-state GDP per capita by 4%.

Jamison, Lau and Wang (2003: 4) concluded that moving from fully closed to fully open trade policies raises growth by 1.7% per year, mostly through technical progress.

Bosworth and Collins (2003: 32) concluded, to their surprise and contrary to Jamison, Lau and Wang (2003) and most of other literature, that trade openness operates through capital accumulation rather than total factor productivity.

Possible conclusions and stylized facts for the IFs project are:

First, R&D may have both fairly fast and longer-term gains (probably associated heavily, respectively, with private and public spending). IFs represents public spending only and uses it as proxy for total spending.

Second, the magnitudes of impact of higher R&D spending appear in many studies to be very high, with an increase in spending of 1% of GDP generating between 0.78-2.0% in higher growth. These returns are at least twice those reported elsewhere for education and health spending, and they should probably be treated very carefully. Given that scientists and laboratories are stocks that need to complement or manifest the higher spending flows, translating higher spending flows into faster growth should be understood to be much more complicated and slower than simply allocating funds. Given the research results, it is probably justifiable to link at least small levels of increase in government spending directly to productivity, even logically there ought to be time lags, especially for larger increases.

Third, the linkage between trade openness and productivity appears substantial. If we again assume that steady-state effects play out over 10-15 years, it appears that the OECD result would indicate that a rise of trade relative to GDP by 10% would increase economic growth by about 0.3% per year. This appears roughly consistent with, but perhaps a little more conservative than the Jamison, Lau and Wang observation of 1.7% gain for countries moving from fully closed to fully open trade (if that shift increased trade over GDP by 30% on average, the growth return to a 10% increase would be somewhat more than 0.5% per year).

5.7 A Quick Reality Check

Although it is difficult to believe that any society could achieve it, would what happen if a country were to succeed in pushing forward on all of the above fronts, so as to achieve levels on each of the drivers that were significantly above mean levels, perhaps about one standard deviation in each category? For this thought experiment, let us assume that the impacts are additive and that the efforts in all areas do not significantly damage the economy elsewhere. With respect to human capital, a country that spent a full percent more than average on both health and education, and that managed in the process to add 1 or more years to average education and life expectancy levels, could expect perhaps to add about 2% to its economic growth rate. If it had governance quality that was a standard deviation or so about the mean, coupled with unusually high levels of economic freedom and trade, it might add about another 2%. If its infrastructure were a standard deviation above the average, it might add as much as 3%. And if it added a percent of GDP to its R&D spending, it might add a good, solid 1% more. In total that would increase productivity growth rate by about 8%.

Let us further posit that we have a system leader with productivity growth of about 1.5-2% and that such a base is assumed to be the base rate for all other countries in the system that are at the mean level with respect to the drivers above. This would create a system in which the average country were neither catching up with nor falling further behind the system leader in per capita terms. Such a system is what most of those who study global growth see and it is the basic structure of productivity representation within IFs.

Yet some countries will do better than average, and some will do much better. The total of the 2% base systemic growth rate in multifactor productivity advance and the premium from all of the above drivers would be as much as 10%. On top of that, our hypothetical super-country would have growth contributions from labor force and capital stock growth. These could potentially add another 2-5%. Thus growth rates of as much as 12-15% could be possible. This is clearly very unlikely, but not historically impossible, and it gives the system of factors an overall plausibility.

Conclusions

The increased attention to economic growth of the last decade has generated much insight into the process and its drivers. The next chapter moves from taking inventory of those insights to elaborating the modeling structures that can help us better forecast growth.

6. Productivity in IFs: Putting the Pieces Together

This chapter links the drivers of productivity discussed in the preceding chapters (many of which are also elaborated in the companion paper, Part 2) to the forecasting of economic productivity and growth within IFs. In doing so it discusses more generally the production function of IFs and the treatment of multifactor productivity. The chapter begins by reviewing the treatment of MFP within IFs and the typology of factors that drive it within the model (see also Hughes and Hossain 2003 and Hughes with Hossain and Irfan 2004). It then elaborates the details of the implementation of the approach in IFs, a long-term forecasting model of 182 countries.

6.1 Two More Threads in the Literature: Convergence and Complementarity

Overlapping with the huge literature on productivity and growth there is another very large literature around the concept of convergence. The foundational notion is simple: it is easier to adopt than to develop technology; therefore latecomers or laggards have the potential of growing more rapidly than technological leaders and converging with them economically. The elaboration of the arguments is considerably more complex and includes even the possibility that technological innovation is subject to a learning process that may reduce the costs to technological leaders and therefore allow them to maintain or extend their productivity lead.

Much of the literature has itself converged around the proposition that there is a constant potential rate of convergence of laggards to leaders that is near 2% per year of the differential of GDP per capita between them (see de la Fuente 2002: 20-21). Dang, Anatolin and Oxley (2001: 5) report 1.75% within and across OECD countries. The direct mechanism for the productivity increase is argued to be some combination of the replacement of older and less productive capital with newer and more productive capital (Baumol 1986) and the growth of human capital, social capability, and scientific/engineering expertise for the use of more productive capital and practices (Furman and Hayes, undated). These mechanisms set the stage for the conditionality of the convergence process; clearly, societies that are not able to replace old capital or efficiently use new capital will not converge with system leaders.

As we move into describing the details of the operationalization of productivity within IFs, it is important to keep in mind that the convergence literature is focused on the potential for convergence, on conditional convergence, not the inevitability of it. In fact, for the global system over the last 200 years, the dominant pattern has been divergence. It is primarily within and among the OECD countries over the last 50 years that convergence has been a strong pattern. Thus we need to represent a world in which both convergence and divergence are possible, both systemically and for specific countries.

The convergence argument, posed universally, would seem to suggest that the poorest countries of the world, such as Haiti and the Democratic Republic of the Congo, could converge to the GDP per capita of the United States at about 2% per year were they only to be endowed instantaneously with the human and social capital of the United States. This may be theoretically possible because it would require annual economic growth rates for 50 years of "only" about 11% for the former Zaire, plus the differential in its population growth rate relative to the US, and of just 10% plus a similar differential for Haiti. But it clearly seems improbable, even were we to posit such a transformation. We can easily imagine the newly educated citizens and modernized governments of these two countries dragged down by their initial economic conditions and the demands of immediate survival, so that in two generations it might be the magical transformation that had disappeared, not the economic differential. Implementation of a convergence process must be reasonable with respect to its potential across extreme differences of development level.

There is a second additional literature that is important, on complementarity of productivity factors. Michael Todaro, in his well-known and well-respected textbook on *Economic Development* (most recently Todaro and Smith 2003) traced the progression of models for thinking about development and underdevelopment. Perspectives have moved from the focus on capital stock and investment (emphasized by both the stages-of-growth model of W. W. Rostow and the Harrod-Domar growth model), to ideas of structural transformation elaborated by both Hollis Chenery and the two-sector models of W. Arthur Lewis, to consideration of system effects in dependence theory and theory of dualism, to the emphasis on free markets and market-friendly policies of the neo-classical counterrevolution, and with Solow to technology in addition to capital and labor.

Solow (1956, 1957) recognized that the then-standard Cobb-Douglas production function with a constant scaling coefficient in front of the capital and labor terms was inadequate, because the expansion of capital stock and labor supply cannot account for most economic growth. It became standard practice to represent an exogenously specified growth of technology term in front of the capital and labor terms as "disembodied" technological progress (Allen, 1968: Chapter 13). Romer (1994) began to show the value of unpacking such a term and specifying its elements in the model, thereby endogenously representing this otherwise very large residual, which we can understand to represent the growth of total factor or multifactor productivity.

Most contemporary approaches to growth and development build in some way on Solow's work, and as noted earlier, on Romer's elaboration of endogenous growth theory or new growth theory. The approach that has characterized International Futures owes much to it. Yet as Todaro and Smith discuss, attention has turned recently to complementary investments in such economic drivers as "human capital (education), infrastructure, or research and development" (2003: 148). Barro and many other authors that were discussed earlier in this manuscript exemplify this attention to complementarity in their work empirically, attempting to explain productivity as a function of multiple, interacting inputs. So, too, does Sen's emphasis on enhancement of development prospects via many inputs. In a sense, such emphasis on complementarity ties us back to Chenery's notions of structural transformation; in many respects all of the evolution in explaining growth has been evolutionary and cumulative.

The approach to understanding productivity and modeling its advance within IFs should build on this notion of complementary inputs. The basic presumption is that there must be a pattern of advance on many fronts and that significant lag on any one can significantly slow progress.[19] Thus advance with respect to education and human capital more generally, with respect to good governance and market-supportive policies, with respect to infrastructure, and with respect to the adoption/development of knowledge must all proceed in economic development. Big pushes might occur in some areas as opportunities develop, but if other areas fall too far behind the costs for development will be substantial.

6.2 Productivity and Production in IFs: The Basic Structure

Recognizing the importance of endogenizing productivity, there was a fundamental choice to make in the development of IFs. One option was to keep the multi-factor productivity representation very simple, perhaps to restrict it to one or two key drivers, and to estimate the endogenization as carefully as possible. Suggestions included focusing on the availability/price of energy and the growth in electronic networking and the knowledge society.

A second option was to develop a representation that included many more factors known or strongly suspected to influence productivity and to attempt a more stylistic and algorithmic representation of the function, using empirical research to aid the effort when possible. The advantages of the second approach include creating a model that is much more responsive to a wide range of policy levers over the long term. The disadvantages include some inevitable complications with respect to overlap and redundancy of factor representation, as well as considerable complexity.

Because IFs is a policy-oriented thinking tool and because many forces clearly do affect productivity, the second approach was adopted, and the production function has become an element of the model that will be subject to regular revision and enhancement. IFs groups the many drivers of multifactor productivity into the four categories discussed in earlier chapters, recognizing that the categories overlap somewhat. The base category is one that represents the elements of a convergence theory, with less developed countries gradually catching up with more developed ones. The four other categories incorporate factors that can either retard or accelerate such convergence, transforming the overall formulation into one of conditional convergence.

1. Human capital quality. This term has two components, education and health. As discussed earlier, IFs looks at both stocks of each (years of education and years of life expectancy) and expenditures as a portion of GDP.

2. Social capital quality. This term has two components also, quality of governance and policy orientation. Representation of the quality of governance, as discussed before, builds on the tripartite division into the process of leadership selection and decision

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[19] In an e-mail on the Millennium Project list-serve (May 28, 2004), Jerome Glenn made a similar point in discussing the Copenhagen Consensus's attempt to prioritize development-oriented interventions. He argued that a cross-impact analysis of the 15 challenges suggests that the interaction effects are so highly significant that their collective impact has the character of a multiplication: "a zero in any one gets you a zero at the end."

making (the democracy level), the effectiveness of decision-making, and the respect citizens have for government (including perceived corruption levels). The policy orientation focuses on economic freedom levels.

3. **Physical capital quality**. IFs looks to three measures of infrastructure for the foundation of the approach here: electricity, roads, and internet use. Robert Ayres[20] has correctly emphasized the close relationship between energy supply availability and economic growth. For instance, a rapid increase in world energy prices essentially makes much capital stock less valuable. IFs uses world energy price relative to world energy prices in the previous year to compute an energy price term.

4. Knowledge creation and diffusion. This term potentially has two components, corresponding separately to the creation and diffusion of knowledge. In reality those two components are jointly driven by many variables, including R&D and aspects of economic connection or integration such as trade and foreign direct investment.

6.3 Operationalizing the Forecasting of Productivity

There are two foundational elements in the approach taken by IFs: the specification of **basic productivity growth rates** and the **representation of the productivity drivers** for deviation around the basic growth rates. This section will discuss those elements and then turn to some of the important elaborations of the approach.

Basic Productivity Growth Rates. We exogenously set core rates for both the systemic leader (identified now as the United States) and other countries. With respect to deviation around those rates, we use the stylized facts and conclusions about drivers of productivity that have been extracted from the literature to drive them. Both of these two foundational elements deserve some explanation.

We noted earlier that the rate of long-term non-farm multifactor productivity growth rate in the U.S. was about 1.6%, although it was considerably slower in the late 1970s through the early 1990s and somewhat faster in the late 1990s. Such historic information is used to set basic future rates. These can vary by sector and the ICT sector is assigned considerably higher rates of current productivity growth. Variation in these rates for the system leader are fundamentally important, because they significantly influence long-term growth prospects; many scenarios involve alternative specifications of them and scenarios can even involve variable specification of them over time.

It is important to keep an eye on the implications that setting basic productivity growth rates for other countries has for the overall behavior in forecasts of the global system. For example, what would be the implications of an overall pattern of productivity gains for technology-follower countries in the range of 1.75-2% per year? If the base case of the model were to build in future rates within this range, on which much of the convergence literature focuses, and if it were to set productivity growth for the systemic leadership at about 1.6%, there would obviously be slow convergence of the global

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[20] Personal interaction in the course of the TERRA project.

system. Such convergence is a pattern that this author believes has empirically begun to emerge, reversing two centuries of global divergence, but there is much debate about it; many observers remain more pessimistic and foresee continued global divergence or at least lack of convergence (the edited volume by Held and McGrew 2003: 421-482 includes a number of competing interpretations of evidence).

IFs handles the uncertainty that characterizes this debate by setting the basic rate of multifactor productivity growth for all countries at the same rate as the system leader. This foundational element therefore represents neither convergence nor divergence.

Productivity Drivers. The other foundational element of the operationalization of productivity in IFs is the representation of productivity drivers, related to characteristics and policies of countries. That representation clearly is linked to the stylized facts and conclusions drawn earlier from the productivity literature.

The basic approach to doing this may seem obvious. The stylized facts collected earlier provide statements about the degree to which extra years of education or better governance give rise to faster growth or, conversely, the degree to which shortfalls on such drivers of productivity retard growth. In operationalizing these insights, however, the question of reference point immediately comes up. Extra years of education or better governance relative to what? The literature on productivity generally looks to a mean value across the system. In estimation of the impact of drivers that literature then generally computes the statistical impact for growth rates of a country's being some distance (as measured by individual years of education or life expectancy or by standard deviations) from that mean.

Imagine, however, the implications of forecasting growth of countries around the world were we simply to assign productivity growth impetus to all of them based on distance from global means. Obviously, Sub-Saharan African countries would have large negative contributions from nearly all of the drivers and OECD countries would have large positive contributions. In fact, given the magnitude of the stylized facts collected earlier, Sub-Saharan African countries would generally have negative growth rates and the OECD countries would have very large positive ones.

Reference Points for Drivers. There are two alternative approaches with respect to the reference points. One would be to look at changes in the drivers relative to the starting point of countries and to calculate the change in their productivity growth rates relative to long-term patterns. Thus additional years of education or improved governance in Mali would contribute to acceleration of growth in an understandable way. An obvious weakness of this approach in a long-term dynamic simulation is that continued growth in years of education would continue to accelerate growth rates, which would likely set up a positive feedback loop since higher GDP would, in turn, facilitate expansion of education. The growth rates would accelerate indefinitely and perhaps very sharply unless the reference point were changed from initial values of the drivers to moving average values for them. In an earlier formulation, IFs used such an approach.

A second approach, however, is to control for level of development in the establishment of the reference point. More specifically, a cross-sectionally estimated function can identify the typical levels for years of education or quality of governance, which will be very different for the Sub-Saharan countries and OECD countries. This approach is, interestingly, very much related to the arguments of Jeffrey Sachs in calling for attention to relative performance on variables such as governance, not absolute performance.

This second approach has been implemented more recently in IFs and will be elaborated in more detail below. It helps in the representation of countries, like Botswana, that have generally had good governance relative to its equally-poor peers, as well as in the representation of Brazil, that has a low level of education relative to its middle-income peers. And it greatly helps in identifying changes in the reference points as countries change their levels of development, for which IFs has used GDP per capita at purchasing power parity as a proxy. Thus the use of relative reference points helps in the forecasting enterprise both across countries and across long periods of time.

Standard Errors Relative to Reference Points. More specifically, IFs looks at the typical patterns across the typology of productivity drivers at different levels of development (using GDP per capita at PPP as a proxy for development level). IFs attempts to represent the impact on productivity that deviation from typical levels will have, both the positive contributions to which exceeding those levels will give rise and the penalties for productivity that falling behind those levels will impose. Instead of using standard deviations from systemic means, we look to standard errors of estimates from the cross-sectional relationship.[21] The formula for the standard error of the estimate is, course, much like that of the standard deviation, substituting the predicted value for the mean value:

$$\sigma_{est} = \sqrt{\frac{\Sigma(Y-Y')^2}{N}}$$

To implement this approach IFs draws upon cross-sectional relationships of each factor in the production function with GDP per capita at PPP. The typical approach to examining productivity is econometric and often even linear (looking, for example, at how much additional years of secondary education for males contribute to productivity). The approach in IFs is more structural and algorithmic. As such, it is, quite frankly, not amenable to simple statistical estimation. Instead, we rely, as has been described, on mining the estimations and stylized facts from other studies for a general idea of the likely responsiveness of productivity on each factor when countries are approximately in overall structural equilibrium (which is what the typical patterns are assumed to be).

Although the discussion here has been about standard errors, the approach within IFs does not always rely on those for parameterization. Much of the productivity literature

[21]Ben Lockwood (2004) suggested a similar approach in thinking about elements of a globalization index. He argued that at least some of those, such as trade openness, should be relative to level of GDP. He suggested that rather than using trade/GDP, it would be best to create a regression against GDP size and then to look at the residuals as evidence of greater or lesser openness.

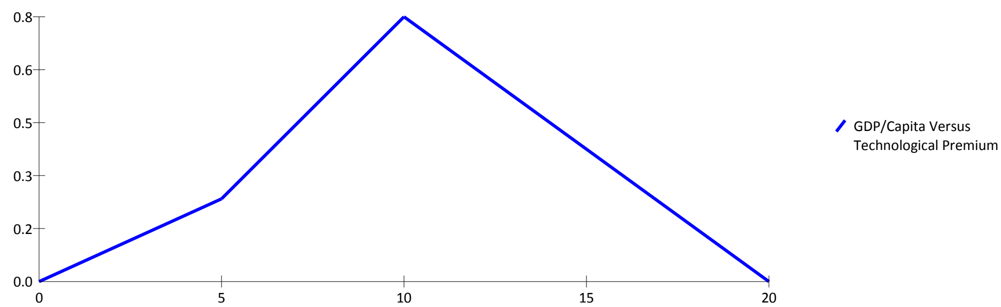
links standard units of the driver variables (such as an extra percent of spending on education, health or R&D) to changes in economic growth. In those cases the formulations in IFs do the same.

Additional Elements: Maintaining Historic Growth Patterns. There are some additional important elements in the structural and algorithmic approach in IFs. One is the reconciliation of computed productivity growth using the analysis of drivers with the actual patterns of long-term growth exhibited in data. The IFs system incorporates a data base of variables for all countries from 1960, when possible, and initializes economic growth rates for countries based on their performance in the most recent decade (weighting the last half of the most recent decade more heavily than the first half). It calculates an apparent growth in productivity from that growth rate and the growth patterns in the other terms of the Cobb-Douglas formulation, notably capital and labor. That apparent MFP growth term can be compared with the expected MFP growth based on the aggregation of computations with the drivers. Although it would be possible to forecast growth for all countries using only the projected growth rate, that would result in a large number of transients in the system from recent data because there clearly are factors that affect growth not represented in the typology of drivers. Instead, IFs uses the apparent MFP growth rate as a base and uses changes in the rate computed from drivers to change that base over time. Over time, the model allows the base growth rate to converge from the initial /historical condition to the computed rate.

Additional Elements: Convergence Pattern Considerations. There is one more important structural or algorithmic element to the approach in IFs. As described to this point, the forecasting system would produce a world in which the present level of systemic inequality would be little changed over time. Some countries, through movement toward good or better policies, would be able to catch up partly or totally with system leaders. Others would fall further behind. But, on average, positive and negative deviations of the drivers around the typical cross-sectional patterns should balance out and preserve the overall systemic distribution. That may be a reasonable base for forecasting, given that there is, as indicated before, such a large debate about whether global inequalities are shrinking or growing.

Yet IFs has introduced two mechanisms that allow change to that forecasting pattern. The first is scenario analysis. Users of the system can simply change the growth in MFP exogenously for any or all countries (the parameter is mfpadd). They can also intervene to change the patterns of the drivers for MFP and growth more generally in ways that would reshape the global distribution. For instance, a user could create a scenario around a global compact, like that called for in the Millennium Development Goals, that would enhance education and health, improvement governance, improve infrastructure and raise trade in developing countries, as well as transfer substantial resources to them for these and other purposes. In other words, much of the world could in such a scenario away from the historic cross-sectional patterns in a growth-enhancing direction. That would create a world of considerable convergence.

The second mechanism is also discretionary for users of the system, but does, in fact, build a degree of convergence into the base case. The convergence literature tends to focus almost entirely on middle to high income countries. And it is those countries that tend to have made the structural transformations and laid the foundations for such catch-up. The Newly Industrializing Countries of the 1980s and 1990s, including now China, seem to have prepared themselves for take-off over many years. It short, it seems likely that there is a kind of convergence or technological premium that should apply to middle income countries. That prospect was discussed in some literature of the 1970s. IFs represents it, in a conservative fashion, giving the model user the options of eliminating it or refining it. The figure below shows that a premium of up to 0.8% is added to economic growth as GDP per capita (represented in thousands on the X-axis) reaches $10,000.



The above function will result in some convergence in the global system, with that occurring primarily for countries in the middle-income portion of it or who grow into the middle-income range over time. The function can be changed by the user.[22] Some may prefer that the tail at the low end of GDP per capita actually go negative, resulting in divergence of condition between richest and poorest in the system. Others may prefer that it be flattened or even eliminated altogether. Again, alternative scenarios are important to the IFs approach.

[22] The function is named "GDP/Capita Versus Technological Premium" and can be altered from the Self-Managed Scenario Analysis (selecting Change Selected Bivariate Functions).

6.4 Using IFs to Analyze Productivity Drivers

The IFs system has a window called the Development Profile (see figure below). This screen helps the user investigate the status of any given country or grouping of countries with respect to the level of key productivity drivers for the country or country set, the typical or expected values for those drivers, and the number of standard errors that the actual values are away from the expected values.

Development Profile

Continue Using Regions

Countries or Regions: Afghanistan Select Year: 2000

Select File: 0 - Working File, based on IFSBASE.RUN

	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					-2.522	
Years of Education	1.146	4.438	2.822	-1.167		0.1
Education Expenditure (Log)	3.928	3.928	2.03	0		0.3
Life Expentancy	42.96	59.71	9.861	-1.699		0.1
Health Expenditure (Log)	1	2.725	1.444	-1.195		0.3
Social Capital					-0.2842	
Freedom	5	8.429	4.624	-0.7416		0
Governance Effectiveness (Linear)	1.11	1.881	0.4855	-1.587		0.5
Governance Effectiveness (Log)	1.11	2.009	0.4855	-1.852		0.5
Corruption Perception	2.681	2.681	1.349	0		0.2
Economic Freedom (Log)	5.938	5.938	2.663	0		0.1
Physical Capital					-0.3826	
Road Ntwk/Land Area	0.322	2.216	6496	-0.0003		0.0001
Kilowatt-hours per capita	859	858.6	2466	0.0002		0
Telephones per 1000	1.471	65.21	83.23	-0.7659		0.6
Internet Percent Use	2.609	2.609	9.746	0		0.025
Knowledge					-0.5583	
R&D Expenditures	0.0422	0.1812	0.1039	-1.338		0.5
Economic Integration						0.2

The table above depends on comparing the computed value of the productivity driver values with the expected values at the specific economic development level of individual countries or larger geographic regions. The computed values themselves within the model are dependent of a wide range of formulations. Some, like years of education, come from substantially elaborated submodels of IFs. Others, like governance effectiveness, come from relatively simple formulations. The companion paper to this one, Part 2 of the set on productivity within IFs, provides some detail on many of those computations.

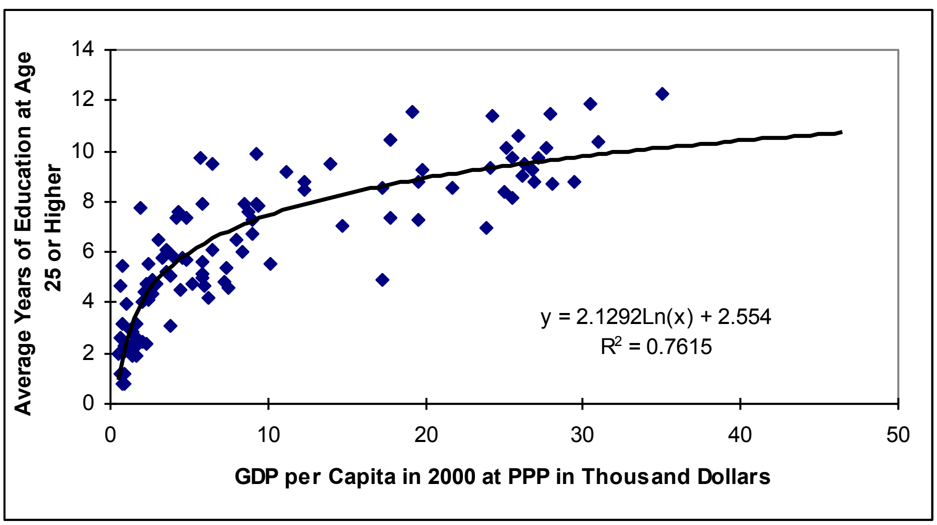
Calculating the expected values is also a critical element of the table above and is essential, along with the parametric specifications, to computing the overall influence of each driver variable category on productivity for the country or region. The next section looks at the cross-sectional analysis that generates the expected value for each element in the above profile.

6.5 Productivity Drivers: Development Levels and Expected Values

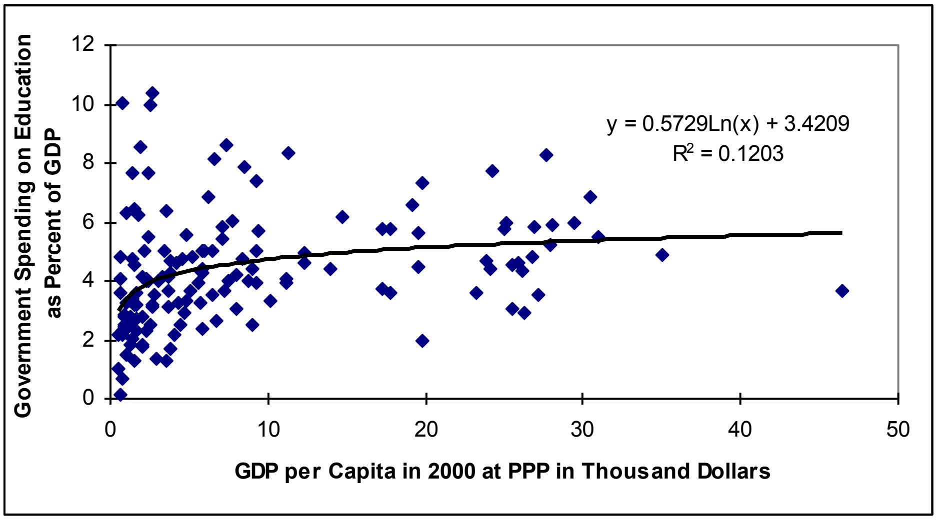
Human Capital: Education

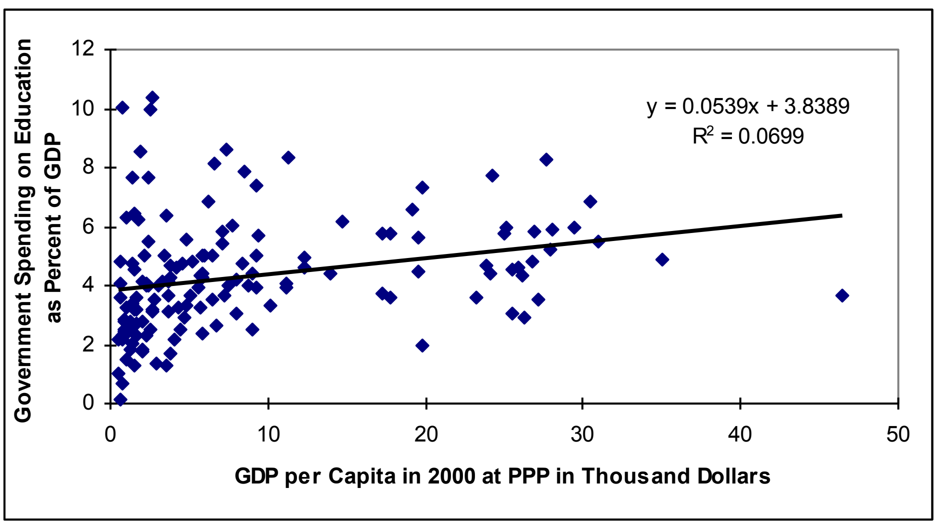
As discussed in the review of productivity literature, there has been increased emphasis on using the years of average education in a population rather than educational expenditures for explaining productivity. The former is more an output measure than an input measure and that is one of the reasons for using it. More importantly in forecasting, however, is the fact that changes in education spending levels should almost certainly not immediately affect productivity – it takes time for those with education to enter the work force and probably more time before their formal educational skills pay off in productivity. The use of a variable such as years of education of the population aged 25 or above automatically builds in such a lag.

The graph below looks at the typical pattern of relationship between GDP per capita (at PPP) and average years of education. The outlier below the line at about $17,000 and only 4.91 years of education is Portugal, which thus appears rather "undereducated" relative to the income that its membership in the European Union has helped it achieve. In contrast the outlier above the line at $1,900 and 7.78 years of average education is Cuba, which underperforms economically because of domestic policy and systemic position, including the economic embargo of the U.S.. Over time, if those deviations from a typical education pattern persist, we might expect Portugal's growth to slow and that of Cuba's to rise. Those are, in fact, the forecasts that the structural representations of IFs described above would produce.

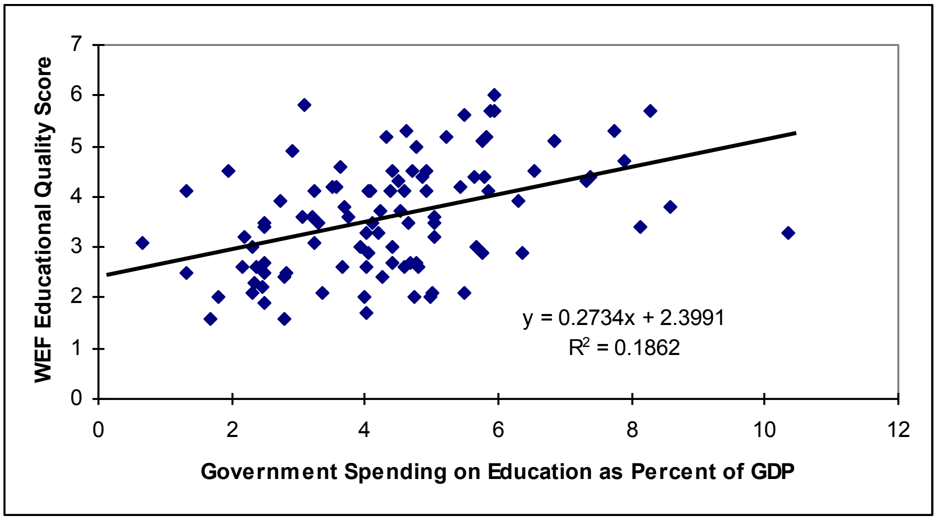


Yet the productivity literature also suggests that expenditure levels, not just average years of education, are important. The two graphs below show logarithmic and linear relationships between GDP per capita and educational spending. In both, the outlier at nearly $20,000 per capita and only 1.95% of GDP devoted to education is the United Arab Emirates, suggesting that low education spending could be a serious future drag on productivity. In the relationships below, the logarithmic formulation tends to have the better fit. For that reason we use it in the model. In addition, however, it logically captures a saturation effect in education spending as a portion of GDP that helps avoid unreasonable expectations for education spending during long-range forecasting as many countries become very rich. We sometimes use logarithmic formulations even when the fit is not quite as good as the linear one.





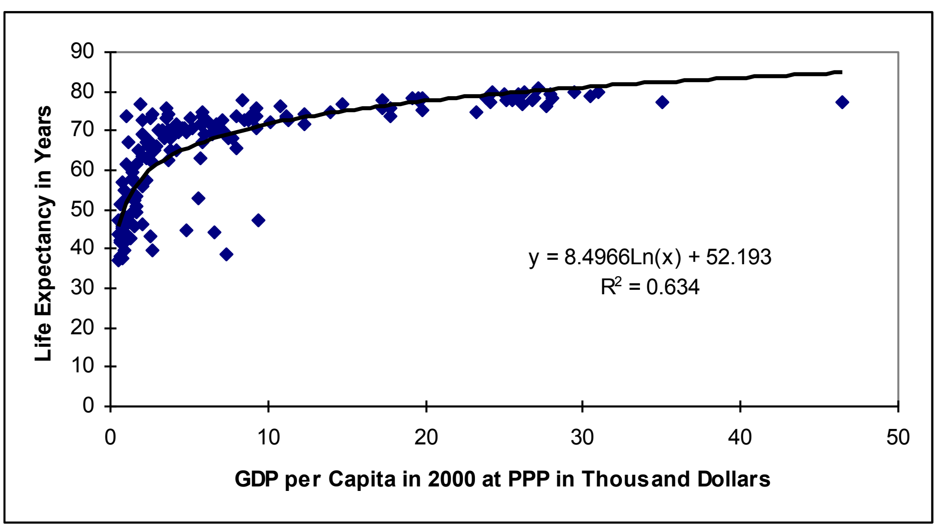
As indicated earlier, one reason for separate attention to educational spending, in spite of the problems it introduces for dynamic forecasting, is the relationship it is sometimes argued to have with educational quality. The graph below shows the relationship between spending as a portion of GDP and the World Economic Forum's measure of educational quality. It suggests some validity for the posited relationship; because the WEF measures are perceptual data based on surveys, however, it is not impossible that the quality perception is, itself, related to spending levels, even if actual quality is not.



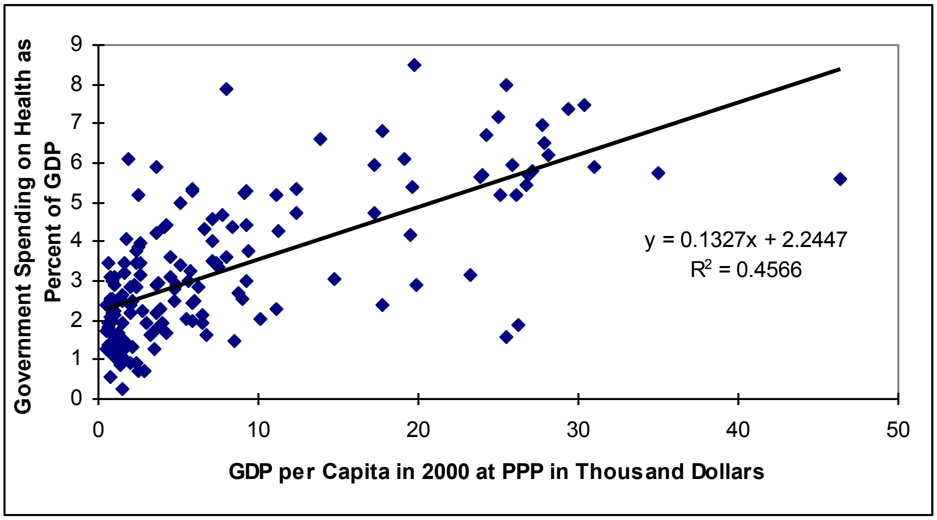
Human Capital: Health

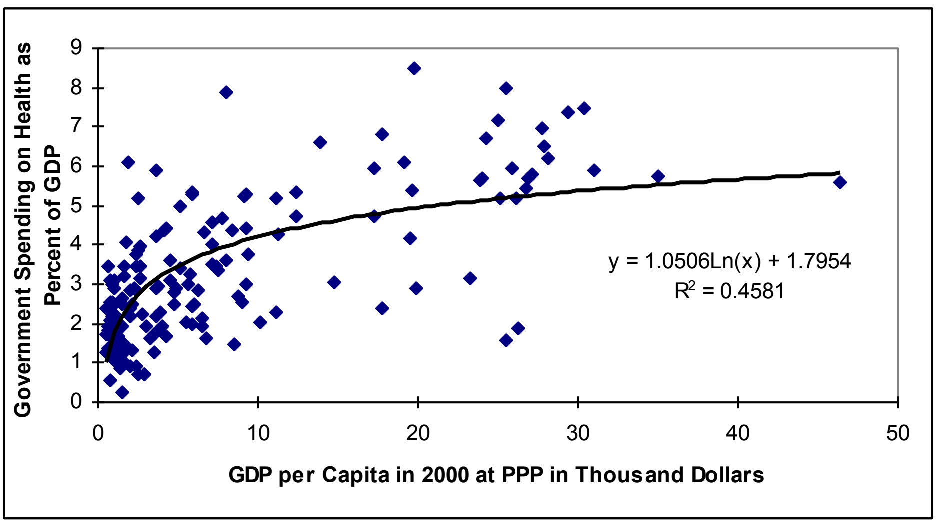
As with education, both outcome/stock and input/flow measures are again used in analysis of the productivity impact of health, namely years of life expectancy and spending, respectively. And as with education there is some reason to question whether higher health spending should be allowed to translate immediately into productivity gains. Yet with higher health spending, some quick reduction of illness of existing workers might be expected, thus making emphasis on a lagged measure less critical. Nonetheless, we again add both to the formulation.

The figure below shows life expectancy at birth as a function of GDP per capita. The outlier at $7,300 and 38 years is Botswana. Clearly this reflects increased mortality from AIDS in recent years. Botswana is often cited as an exemplar of good governance in Africa, but its position on this graph would suggest that substantial set-backs in productivity could be coming.



The two graphs below look at government spending on health as a function of GDP per capita. The relationships tend to be somewhat steeper than those for educational spending. Again, the saturating logarithmic formulation is more theoretically satisfying.





Social Capital: Governance Quality

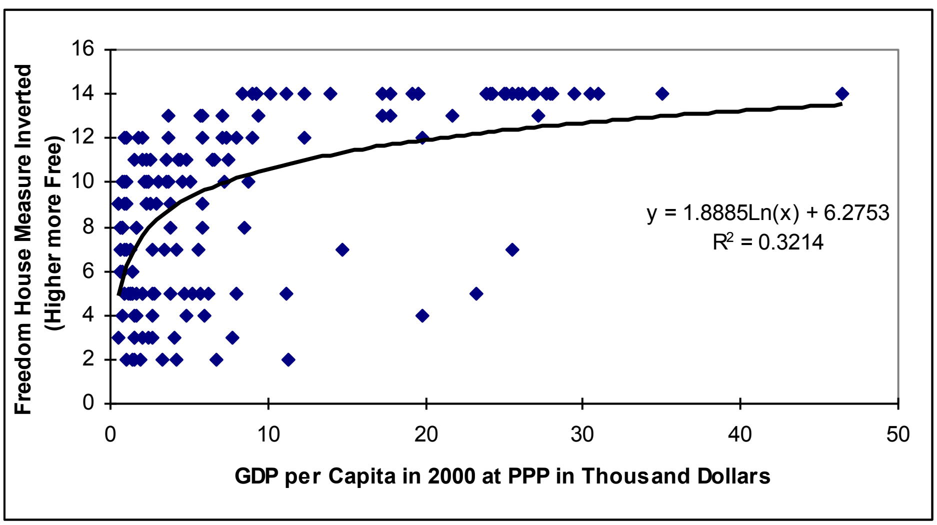
Still again we refer to the three dimensions identified by the World Bank project on governance:

> (1) the process by which governments are selected, monitored and replaced, (2) the capacity of the government to effectively formulate and implement sound policies, and (3) the respect of citizens and the state for the institutions that govern economic and social interactions among them (Kaufmann, Kraay and Mastruzzi 2003: 2).

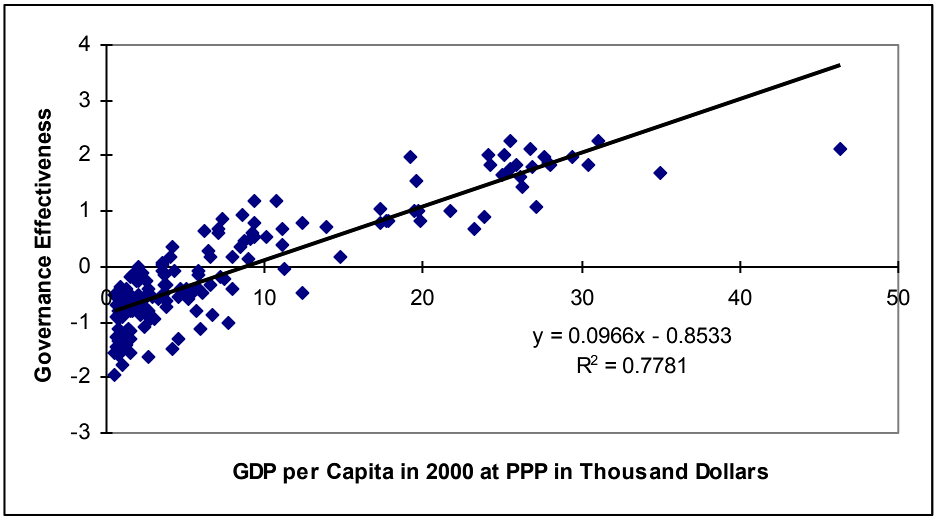
The review in Chapter 2 of literature suggested that democracy, an indicator on the first dimension, has an uncertain and quite possibly negligible relationship to productivity.

That suggests that the basic parameterization of any linkage should be a zero or a very small value – in the base case it is set at 0.0. Nonetheless, it is important to allow model users to work with this linkage and therefore to include a basic relationship with development in the model. Using the Freedom House measures of civil and political liberties, summed into a single index, the baseline cross-sectional relationship in 2000 takes the form of the figure below. The normal scale of Freedom House runs from 14 least free) to 2 (most free). Because higher values are better on essentially all of the drivers of productivity discussed to this point and subsequently, and because there long was confusion on the part of IFs users about the scaling used by Freedom House, the measure in the figure below and in the model was inverted. That is, higher values on it are now more free.

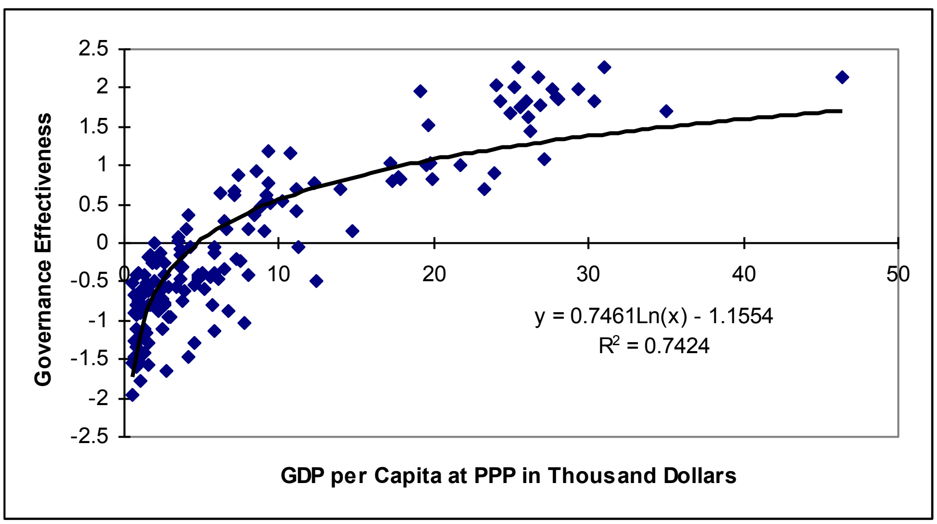
Among the outliers at relatively high GDP per capita are Qatar with a GDP per capita of $23,200 and freedom level of 2, the UAE with GDP per capita of $19,800 and a freedom level of 3, and Singapore with GDP per capita of $25,500 and freedom of 4. This set in itself indicates the reason that greater freedom is not often found to be correlated with greater growth. Similarly, Uruguay is an outlier with a GDP per capita of $9,100 and a freedom level of 12.



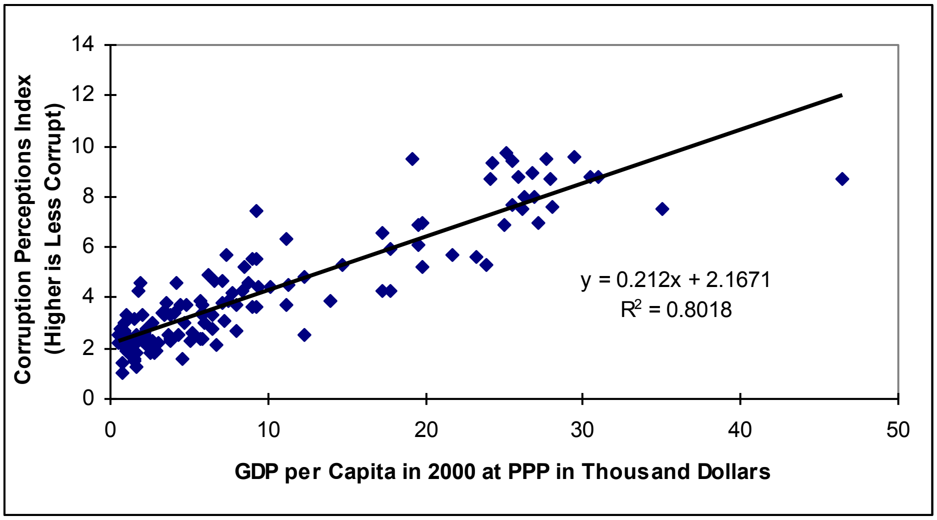
Turning to government effectiveness, a measure tapping the second dimension of the World Bank project on governance, the cross-sectional relationship with GDP per capita in 2000 is shown below. The outlier below the line at $12,400 and effectiveness of only -0.49 is Argentina. Another outlier below the line at $4,100 and -1.47 is Turkmenistan. The outlier above the line at $19,200 and 1.97 is New Zealand.



The logarithmic function below has a slightly lower R-squared than the linear one above. But it probably better represents the saturating character of index at high levels of GDP per capita. And at the lower end of the GDP per capita scale, effectiveness perhaps does truly disappear. Thus in analysis of the expected values for governance effectiveness, the logarithmic function again appears better. In the model, however, a bivariate function is used to actually drive the computation of governance effectiveness – years of education supplements GDP per capita.



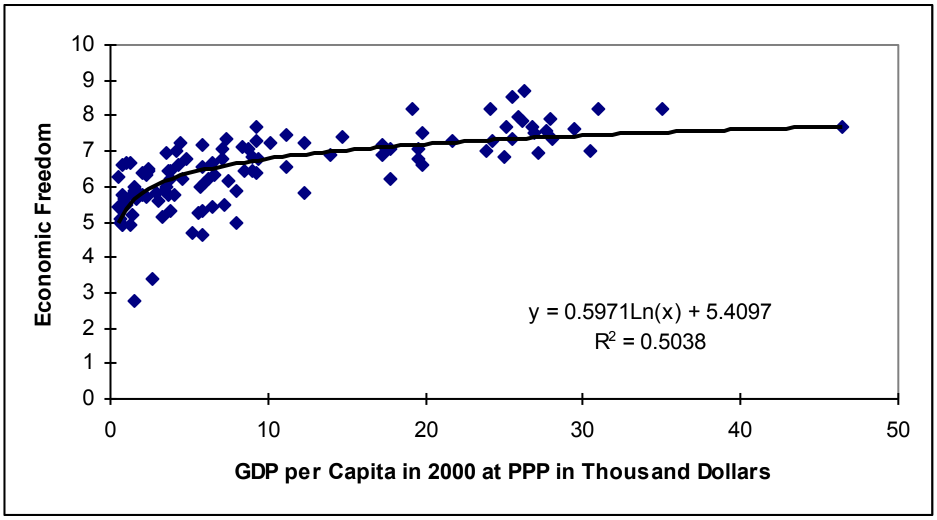
Moving to the World Bank's third dimension of governance quality, the relationship below looks at Transparency International's Corruption Perception Index.

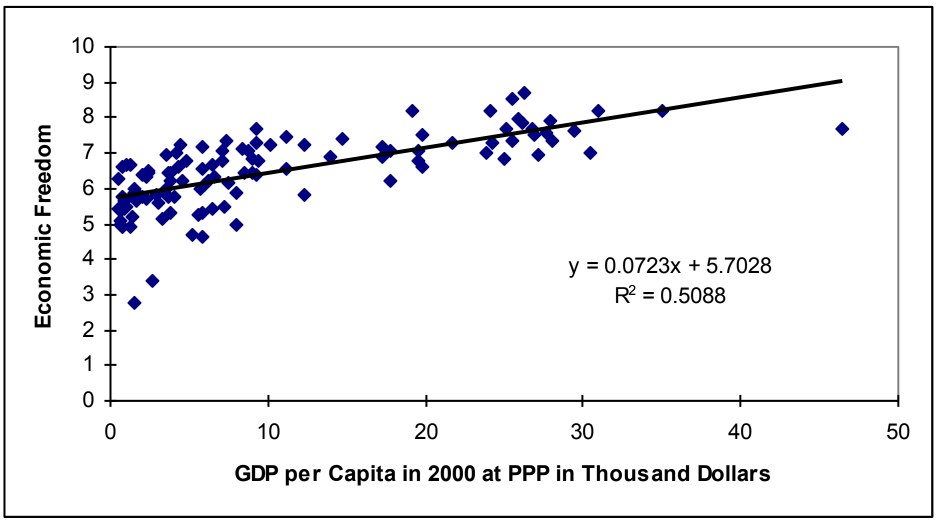


Although the measure saturates at 10, a logarithmic fit is not nearly as good as the one above, having an adjusted r-squared of 0.68 and this is one variable for which the model does use the linear relationship (with output capped at 10, the maximum value of the Transparency International index). Two of the most extreme upward outliers are Chile with a GDP per capita of $9,700 and a corruption measure of 7.4 and New Zealand with a GDP per capita of $19,200 and a corruption measure of 9.5. On the downward side one extreme outlier is Argentina with a GDP per capita of $12,400 and a corruption measure of 2.5.

Social Capital: Economic Freedom

The two figures below relate GDP per capita to the Economic Freedom measure of the Fraser Institute. There are two extreme outliers in the lower, left-hand side of the curve. The one at $1,500 and 2.76 economic freedom is Myanmar and the one at $2,600 and 3.38 is Zimbabwe; in both cases performance on this measure is probably dragging down growth. A sample outlier above the curve, at $780 and 6.60 on the economic freedom scale is Zambia.


Economic Freedom
GDP per Capita in 2000 at PPP in Thousand Dollars
y = 0.5971Ln(x) + 5.4097
R2 = 0.5038

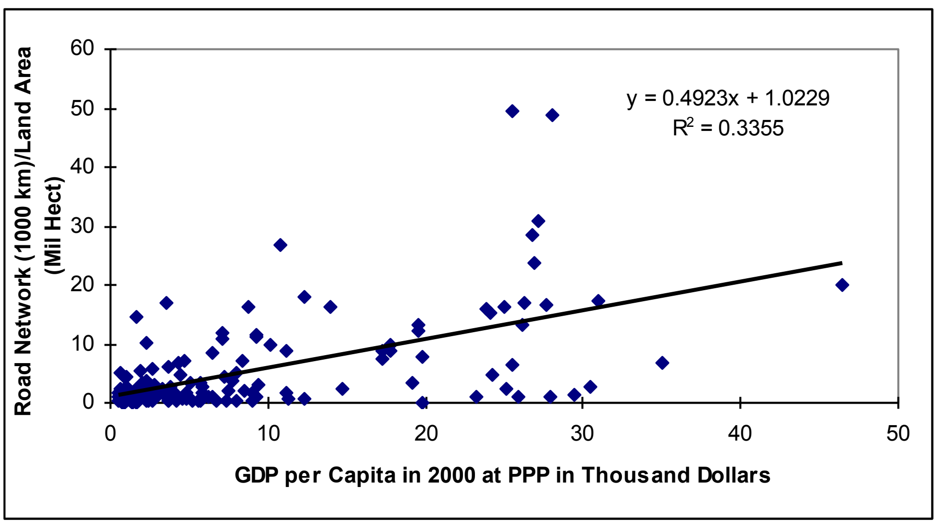

Economic Freedom
GDP per Capita in 2000 at PPP in Thousand Dollars
y = 0.0723x + 5.7028
R2 = 0.5088

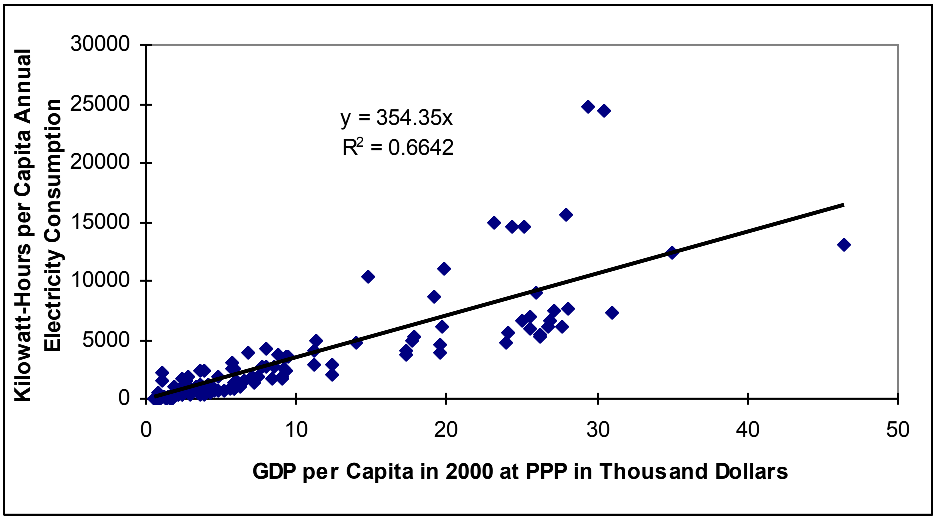
Physical Capital: Infrastructure

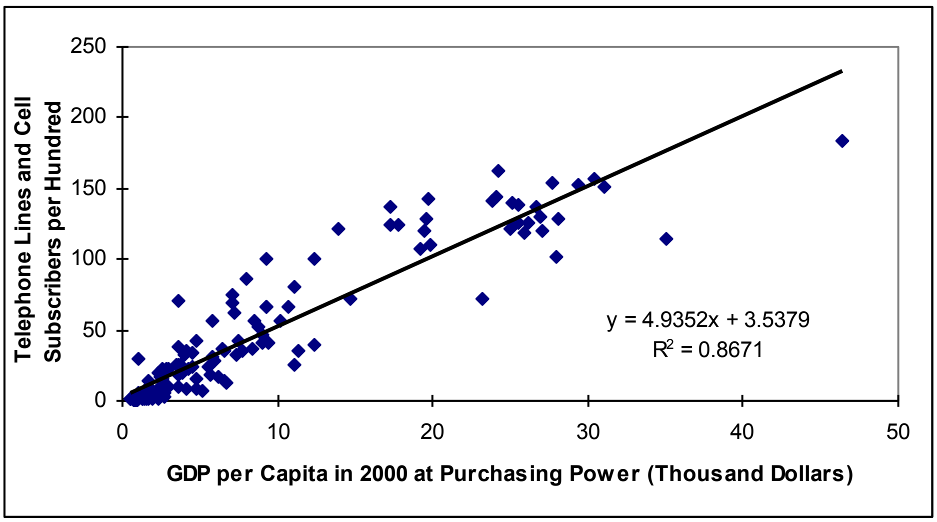
The figures below, showing relationships between GDP per capita and various measures of infrastructure are presented without any commentary. The companion piece (Part 2) provides considerable discussion of them individually and in more aggregate index form. Initially it was anticipated that the infrastructure measures would enter into IFs in index form across several aspects of modern infrastructure. The correlations across those components proved very weak, however (as the separate document discusses), and it is almost certainly better to maintain their separate influence.

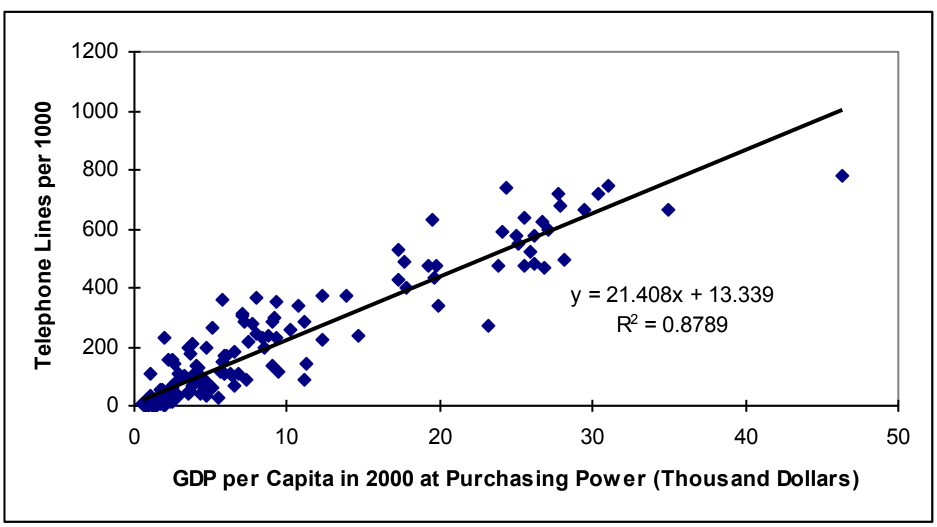
All of the functions in them were forced through the origin to avoid negative intercepts. The IFs model uses a function for internet use computed with 2000 data, even though 2002 data are available, because the model is initialized in 2000. For many relationships, shift of a year or two, in order to get the most recent and best data is of little consequence; but internet use obviously changed greatly over those two years.

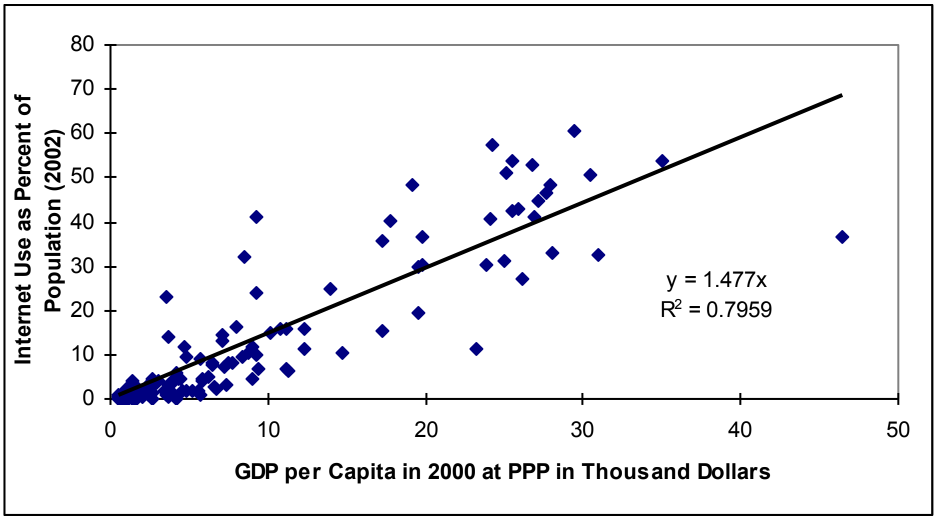
Four of the functions below are used in computing expectations for countries and calculating the impact of deviations from those on productivity. Telephone lines and cell subscribers could be substituted for telephone lines per 1000 and probably should be in the future.




Kilowatt-Hours per Capita Annual Electricity Consumption
30000
25000
20000
15000
10000
5000
0
y = 354.35x
R² = 0.6642
0
10
20
30
40
50
GDP per Capita in 2000 at PPP in Thousand Dollars

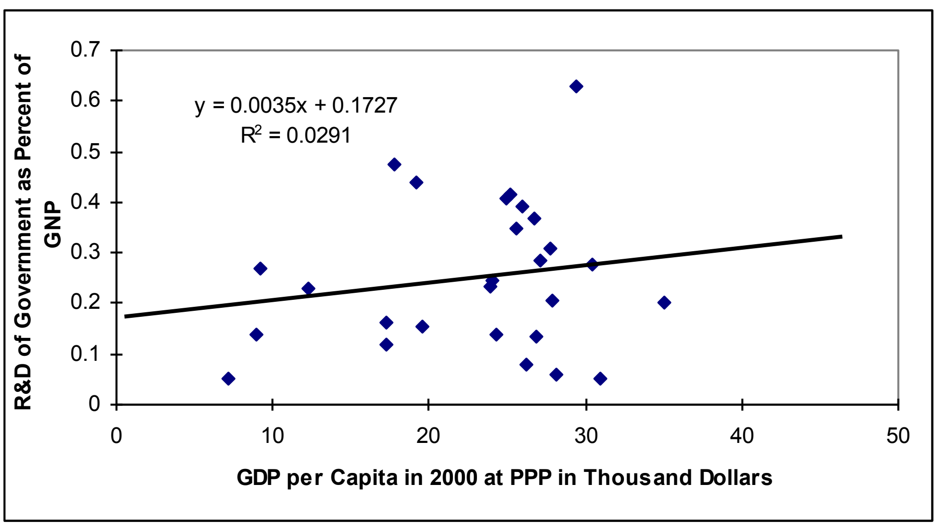

Telephone Lines and Cell Subscribers per Hundred
250
200
150
100
50
0
y = 4.9352x + 3.5379
R² = 0.8671
0
10
20
30
40
50
GDP per Capita in 2000 at Purchasing Power (Thousand Dollars)


Telephone Lines per 1000
1200
1000
800
600
400
200
0
y = 21.408x + 13.339
R² = 0.8789
0
10
20
30
40
50
GDP per Capita in 2000 at Purchasing Power (Thousand Dollars)



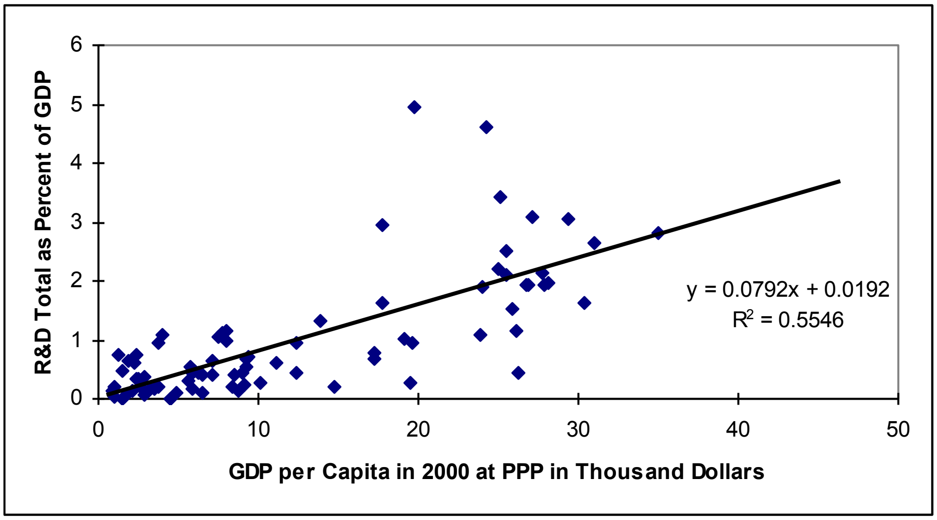
Knowledge Creation and Diffusion

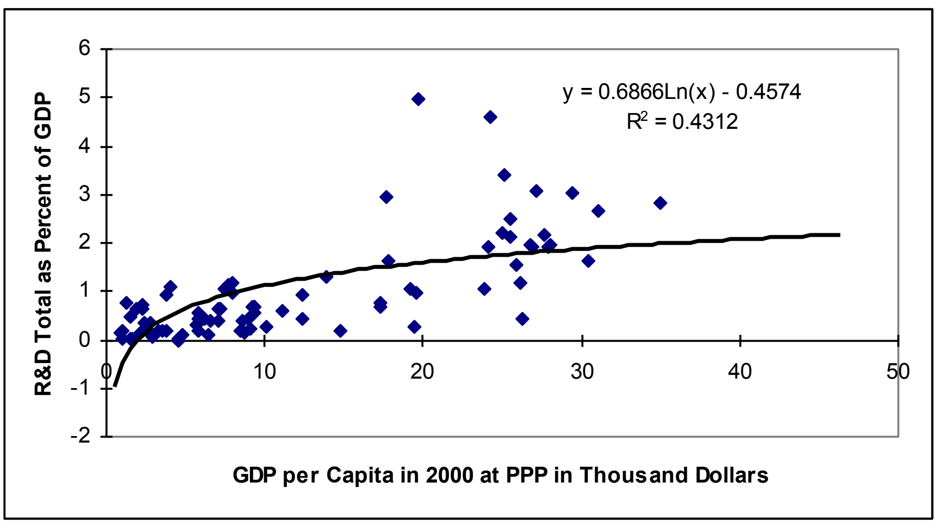
As discussed earlier, many of the variables that drive knowledge creation and diffusion, such as education levels and internet usage, have been treated above. Thus this contribution to productivity focuses on R&D spending as a driver of knowledge creation and economic integration as a driver of knowledge diffusion. The figure below relates GDP per capita to governmental R&D spending. The data for this are very limited, almost entirely to OECD countries.



The above figure is questionable for use in the representation of productivity. First, the data are very skimpy. Second, the relationship is obviously very weak. Finally, and perhaps most important, public R&D is only a small fraction, about 10%, of total R&D. Thus it is not surprising that the productivity literature, especially from the OECD, has found that private and/or total R&D spending is better related statistically to growth rates.

The figures below, focused on total R&D spending, show much stronger relationships with GDP per capita. Because they thus provide a better basis for expected R&D spending and because private R&D is more important in the productivity literature, IFs looks to those functions. In particular, IFs uses the linear function which has a considerably higher r-squared, but bounds values at or below roughly 3%, the level anticipated at a GDP per capita of $40,000.



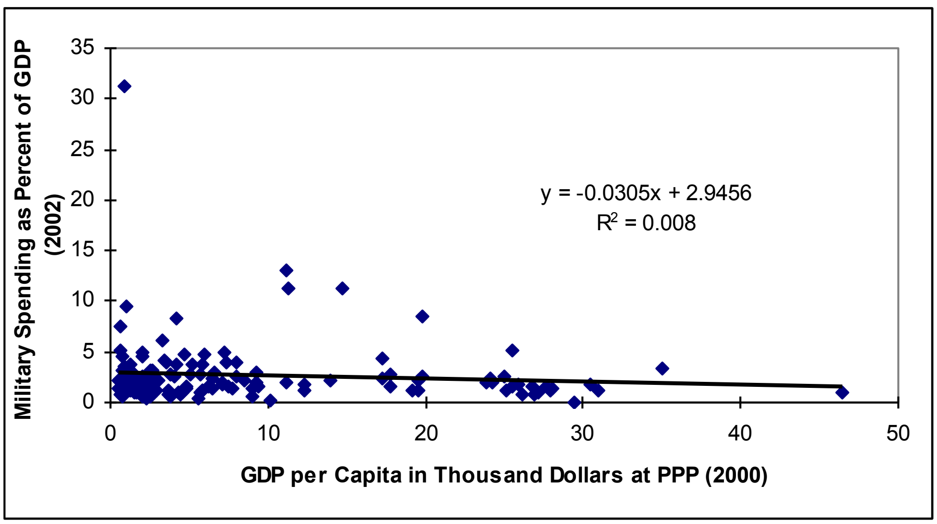


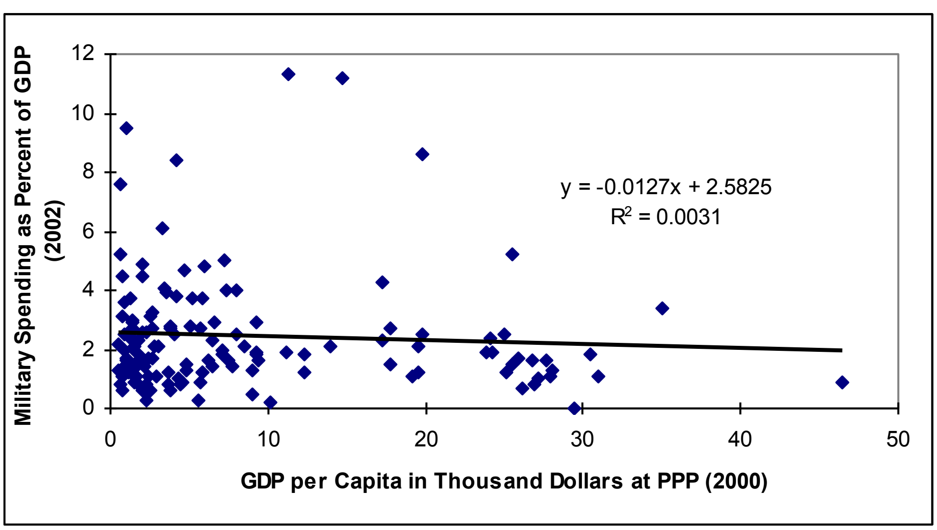
In addition to R&D spending, economic integration (an index based on levels of trade and FDI – see the companion paper for details) is also used as a driver of productivity. It is, however, not really meaningful to have a cross-sectional relationship between GDP per capita and either trade openness or FDI levels. The bivariate relationship with trade openness has an r-squared of less than 0.06. The model could have pursued a multivariate relationship, adding independent variables such as country size, whether or not a country is land-locked, and so on. Efforts to do so suggested that it remains hard to find a strong predictive relationship. It was decided to add economic integration to the driver set for productivity in terms of changes from each country's own initial value.

Thus the reference point for the contribution is not a function and is not shown in graphical form.

An Aside: Military Spending

Although levels of military spending are not normally linked to productivity, and IFs does not do so, graphs above have shown most other major categories of government spending as functions of GDP per capita. The two graphs below therefore show military spending simply to complete the image of how government spending patterns tend to change with GDP per capita. It contrast to the upward sloping curves for other categories of spending, there is a slight downward slope for military spending. In the first graph the extreme outlier is Liberia at 31% of GDP. The second graph removes that country from the portrayal and calculations. Although not shown, the relationship in 1988, before the end of the Cold War, had a higher intercept at 3.3%. In addition, the slope was somewhat flatter; richer countries have harvested somewhat more post-Cold War peace dividend than have poorer countries.





6.6 Changing Productivity Relationships

This section addresses three issues: the parameterization of the production formulation in IFs (look back at the Development Profile table that summarizes the way in which IFs relates computed values of productivity drivers with values expected at different levels of development), the use of that formulation, and possible further steps in its development.

Parameterization. With respect to parameterization, Chapter 5 drew stylized facts and insights from the literature on productivity. Those facts and insights were the basis for the parameterization. In general, however, the values within IFs were chosen somewhat conservatively, because (1) the number of inputs to the production formulation is so great that there almost certainly is some redundancy of specification in our list, an issue to which we will return later, and (2) the implementation in IFs is new and should be tested over time before higher values may be introduced. The table below shows the current parameterization.

	Parameter
Human Capital	
Years of Education	0.3
Education Expenditures (Log)	0.1
Life Expectancy	0.3
Health Expenditure (Log)	0.1
Social Capital	
Freedom	0
Governance Effectiveness (Log)	0.5
Corruption Perception	0.2
Economic Freedom (Log)	0.1
Physical Capital	
Road Ntwk/Land Area	0.0001
Kilowatt-hours per capita	0.000001
Telphones per 1000	0.6
Network Use Percent	0.025
Energy Price	-0.1
Knowledge Creation	
R&D Expenditures	0.5
Economic Integration	0.2

In setting the parameters for the table above, years of education and educational expenditures were considered as a pair. The literature suggests that the former generates 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. In order to emphasize lags between attention to education and economic impact within the forecasts, the parameter for the former was set on the high side of the range, and the parameter for the latter was set low.

Similarly, in setting parameters around health, life expectancy and health spending were treated as a pair. The literature suggests that 1 standard deviation in life expectancy (about 13 years) can yield about 1.4% growth (another study says 1-4%). The IFs parameterization is quite conservative. The literature suggests that 1% of extra spending might yield 0.5% in growth; the parameter is again very conservative.

Turning to governance-related drivers, the literature finds no clear relationship between democracy or freedom and growth; the parameter was set to 0.0. It finds that governance quality (generally focused on the rule of law) yields about 1.2% extra growth per standard deviation improvement, but that some of the effect almost certainly should be via the path of higher investment rates rather than productivity. The effect in IFs was divided between the measure of governance effectiveness (where 1 SE around the function is about 0.5) and corruption (where 1 SE is about 1.3). Again values were set on the low side.

With respect to economic freedom, the literature says that 1 point increase on the Frasier Institute scale yields 0.1-0.2% growth. The value was set at the bottom of that range.

Turning to infrastructure, the literature says that 1 standard deviation improvement in infrastructure overall yields up to 3% extra growth, and that telephones contribute more than power generation or roads. Values on all infrastructure terms were set very low. The standard error for percent of population using electronic networks as function of GDP per capita is nearly 10%, so a value of 0.025 applied to every percentage point deviation from the estimated functions is the equivalent of adding about 0.25% extra growth per standard error. The standard error on telephone lines per 1000 is 83. The parameter for productivity impact is applied to each 100-point deviation from the expected value. Thus a parameter of 0.6 yields 83/100*0.6=0.5% impact on productivity per standard error.

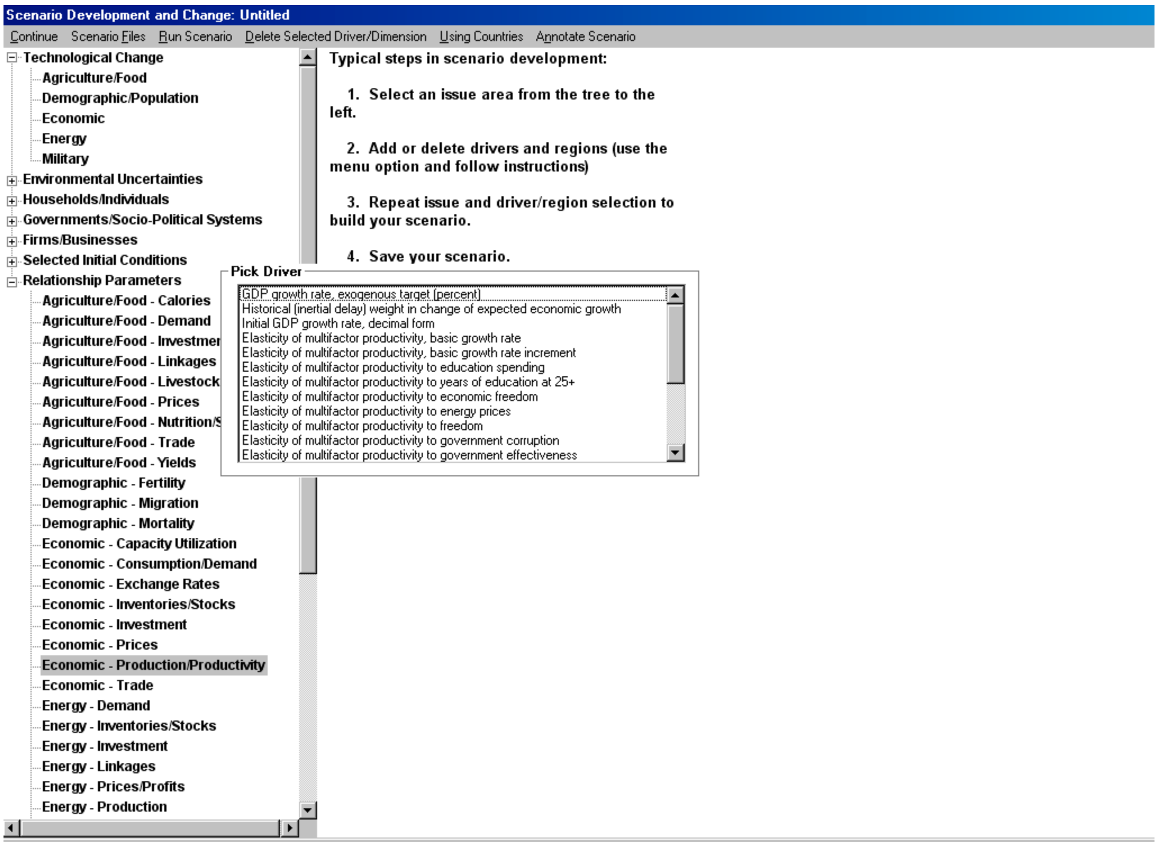
With respect to energy prices, the literature historically has said that an increase of $10 per barrel can reduce global growth by about 0.5%, but that number has recently been suggested to be too high. The parameter was thus set quite a bit lower.

Finally, turning to knowledge creation and diffusion, the literature suggests that a 1% increase in research and development spending as a share of GDP can yield a 2% increase in economic growth. That sounds like a "free lunch," and obviously anything approximating that return to R&D would require a strong foundation also in education and other systems. The parameter was arbitrarily reduced by a factor of four in IFs. We should probably also build in some time lag, possibly via a smoothing of the expenditure numbers.

With respect to economic integration (trade and FDI), the literature suggests that a 10% rise in import share as a portion of GDP yields about 0.3% in growth. We found no stylized facts with respect to the impact of FDI on productivity and growth, but the presumption appears to be that it is significant. The IFs formulation uses an economic integration scale (ECONINTEG) that runs from 0 to 100 as would the import share of

GDP.   We set the parameter for influence on productivity somewhat conservatively relative to the 0.3% figure for import share.

Changing Parameters. From the above discussion, as well as from the earlier review of literature on productivity, it should be clear that the values used in the model are subject to much uncertainty. Users of the model will want to adjust the parameters for their own analysis. The figure below shows the portion of the scenario tree where than can be done.   Specifically, it is under Relationship Parameters, Economic Production/Productivity.



Next Steps. An effort like this in modeling is never done. A number of enhancements can be made over time, many of which should probably be focused on non-linear returns to interventions and to interactions among them. A reasonable presumption is that the investments in any driver of productivity have diminishing returns the further that any productivity-enhancing factor exceeds the typical pattern; at the same time, short-falls on any driver will probably impose increasing penalties as they become larger. Thus, for instance, great investments in education will produce productivity returns, but the creation of many more Ph.D.s than is common at a particular level of development will result in increasing numbers of underemployed doctorate holders rather than economic returns. In contrast, however, it might be reasonable to posit that falling behind typical patterns for productivity-enhancing factors is subject to increasing penalties rather than diminishing ones. For instance, failure to development infrastructure will probably weaken productivity considerably more, the further levels fall behind typical ones.

Anyone involved in development knows that it is an art, not a science, and that recipes that promote a single driver, whether education, health, governance, or R&D, have never been fully satisfactory. Easterly (2001) reviewed many such single-factor recipes and found them wanting, in part because of his focus on them individually. In a lecture attended many years ago by the author of this paper, Charles Lindblom (see 1959) reported tongue-in-cheek on a house search in which he and his wife assigned points to fireplaces, extra cabinet space, windows, and so on; they gave up the method when they realized that a greenhouse had scored the highest. Similarly, development efforts focusing on any one driving factor alone cannot be successful; there is a need for balance.

7. Analysis with IFs

Among others, Jeffrey Sachs has argued that advice by experts with respect to economic performance should be rooted in a clinical analysis focused on the specifics of a country's condition, not a matter of offering blanket prescriptions. The endogenous representation of productivity within IFs and the availability of the Development Profile form makes it easier to undertake such analysis. Similarly, better forecasting the growth of countries can be rooted in analysis of the development profiles.

For instance, sub-Saharan Africa, often discussed as if problems were similar throughout the region, exhibits vast variation. The three profiles below are for Middle Africa, Eastern Africa, and Botswana. Middle Africa is being substantially handicapped by human capital, social capital, physical capital, and knowledge shortfalls.

Development Profile

Continue Using Groups

Groups Afr-Middle **Select Year** 2000

Select File: 0 - Working File, based on IFSBASE.RUN

	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					-0.9267	
Years of Education	3.092	0.4968	2.822	0.9196		0.1
Education Expenditure (Log)	2.95	2.867	2.03	0.0407		0.3
Life Expentancy	46.99	43.98	9.861	0.305		0.1
Health Expenditure (Log)	1.445	0.7803	1.444	0.46		0.3
Social Capital					-0.2267	
Freedom	4.418	12.04	4.624	-1.649		0
Governance Effectiveness (Linear)	1.228	1.683	0.4855	-0.9382		0.5
Governance Effectiveness (Log)	1.228	0.6189	0.4855	1.254		0.5
Corruption Perception	2.181	2.248	1.349	-0.0497		0.2
Economic Freedom (Log)	5.356	4.833	2.663	0.1967		0.1
Physical Capital					-0.2816	
Road Ntwk/Land Area	0.5942	1.21	6496	-0.0001		0.0001
Kilowatt-hours per capita	126.8	134.8	2466	-0.0032		0
Telephones per 1000	3.081	21.49	83.23	-0.2211		0.6
Internet Percent Use	51.96	0	9.746	5.331		0.225
Knowledge					-0.5308	
R&D Expenditures	0.0309	0.174	0.1039	-1.378		0.5
Economic Integration						1.8

Eastern Africa is, on average, much closer to values expected for its levels of development in most dimensions of productivity driver, a large exception being for knowledge creation and diffusion (economic integration is well below expected levels).

Development Profile

Continue Using Groups

Groups: Afr-Eastern Select Year: 2000

Select File: 0 - Working File, based on IFSBASE.RUN

	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					-0.1902	
Years of Education	2.285	-0.3942	2.822	0.9494		0.1
Education Expenditure (Log)	4.398	2.628	2.03	0.8722		0.3
Life Expentancy	43.92	40.43	9.861	0.354		0.1
Health Expenditure (Log)	2.411	0.3407	1.444	1.434		0.3
Social Capital					0.0945	
Freedom	7.348	12.86	4.624	-1.192		0
Governance Effectiveness (Linear)	1.755	1.671	0.4855	0.1733		0.5
Governance Effectiveness (Log)	1.755	0.3046	0.4855	2.987		0.5
Corruption Perception	2.412	2.22	1.349	0.1418		0.2
Economic Freedom (Log)	5.77	4.583	2.663	0.4457		0.1
Physical Capital					-0.1538	
Road Ntwk/Land Area	1.023	1.146	6496	0		0.0001
Kilowatt-hours per capita	201.8	88.74	2466	0.0459		0
Telephones per 1000	6.964	18.7	83.23	-0.141		0.6
Internet Percent Use	44.34	0	9.746	4.55		0.4
Knowledge					-0.7108	
R&D Expenditures	0.0389	0.1736	0.1039	-1.297		0.5
Economic Integration						3.2

Botswana is well above expected values in social capital, but HIV/AIDS has taken a great toll on human capital. One cannot help but wonder about the sustainability of its success with governance in light of the failure of the society on human capital.

Development Profile

Continue Using Regions

Countries or Regions: Botswana Select Year: 2000

Select File: 0 - Working File, based on IFSBASE.RUN

	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					-1.922	
Years of Education	5.349	6.57	2.822	-0.4326		0.1
Education Expenditure (Log)	8.59	4.501	2.03	2.014		0.3
Life Expentancy	38.97	68.22	9.861	-2.966		0.1
Health Expenditure (Log)	3.439	3.777	1.444	-0.2338		0.3
Social Capital					1.032	
Freedom	12	6.475	4.624	1.195		0
Governance Effectiveness (Linear)	3.37	2.284	0.4855	2.237		0.5
Governance Effectiveness (Log)	3.37	2.761	0.4855	1.254		0.5
Corruption Perception	5.7	3.565	1.349	1.582		0.2
Economic Freedom (Log)	7.357	6.536	2.663	0.3085		0.1
Physical Capital					-0.3784	
Road Ntwk/Land Area	0.1756	4.269	6496	-0.0006		0.0001
Kilowatt-hours per capita	2337	2337	2466	0.0001		0
Telephones per 1000	91.48	154.5	83.23	-0.7573		0.6
Internet Percent Use	7.101	7.101	9.746	0		0.025
Knowledge					-0.5964	
R&D Expenditures	0.1083	0.1958	0.1039	-0.8421		0.5
Economic Integration						0.2

Turning to large emerging countries, the figures below look at the BRICs: Brazil, Russia, India, and China. Brazil shows some substantial weakness on human capital (even in an analysis that does not focus on distributional aspects of it). With respect to social capital its level is roughly neutral and it benefits on physical capital from telephone levels that exceed those expected at its development level. On knowledge creation and diffusion, it benefits somewhat from R&D spending, but that is more than offset of lower than expected economic integration.

Development Profile

Continue Using Regions

Countries or Regions Brazil **Select Year** 2000

Select File: 0 - Working File, based on IFSBASE.RUN

	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					-0.504	
Years of Education	4.558	6.608	2.822	-0.7265		0.1
Education Expenditure (Log)	4.029	4.512	2.03	-0.2377		0.3
Life Expectancy	68.07	68.37	9.861	-0.0302		0.1
Health Expenditure (Log)	3.381	3.796	1.444	-0.2872		0.3
Social Capital					0.0259	
Freedom	11	6.44	4.624	0.9862		0
Governance Effectiveness (Linear)	2.28	2.295	0.4855	-0.0314		0.5
Governance Effectiveness (Log)	2.28	2.775	0.4855	-1.019		0.5
Corruption Perception	3.9	3.59	1.349	0.2294		0.2
Economic Freedom (Log)	6.169	6.547	2.663	-0.1417		0.1
Physical Capital					0.2569	
Road Ntwk/Land Area	2.02	4.328	6496	-0.0004		0.0001
Kilowatt-hours per capita	1878	2379	2466	-0.2032		0
Telephones per 1000	217.8	157.1	83.23	0.7303		0.6
Internet Percent Use	2.945	7.23	9.746	-0.4397		0.025
Knowledge					-0.4632	
R&D Expenditures	0.2108	0.1962	0.1039	0.1407		0.5
Economic Integration						0.2

Russia, below, has a fairly strong physical capital/infrastructure structure for its level of development, but fails on all other dimensions. In particular, it is falling behind on human capital. Although its population currently has a reasonably high level of education, it is spending less than the typical pattern and its life expectancy and health spending also lag.

Development Profile

Continue Using Regions

Countries or Regions Russia **Select Year** 2000

Select File: 0 - Working File, based on IFSBASE.RUN

	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					-0.8814	
Years of Education	6.717	6.754	2.822	-0.013		0.1
Education Expenditure (Log)	3.073	4.551	2.03	-0.7282		0.3
Life Expentancy	65.34	68.95	9.861	-0.3661		0.1
Health Expenditure (Log)	3.623	3.868	1.444	-0.1692		0.3
Social Capital					-0.5438	
Freedom	5	6.306	4.624	-0.2825		0
Governance Effectiveness (Linear)	2.1	2.341	0.4855	-0.4964		0.5
Governance Effectiveness (Log)	2.1	2.826	0.4855	-1.495		0.5
Corruption Perception	2.7	3.691	1.349	-0.7343		0.2
Economic Freedom (Log)	4.991	6.587	2.663	-0.5996		0.1
Physical Capital					0.4576	
Road Ntwk/Land Area	0.3077	4.561	6496	-0.0007		0.0001
Kilowatt-hours per capita	4181	2547	2466	0.6628		0
Telephones per 1000	243.3	167.2	83.23	0.9137		0.6
Internet Percent Use	7.74	7.74	9.746	0		0.025
Knowledge					-0.524	
R&D Expenditures	0.2329	0.1979	0.1039	0.3369		0.5
Economic Integration						0.2

Looking at India, both human and social capital, particularly the latter, are quite strong. And although R&D expenditures are above the expected level, the low level of economic integration with the rest of the world is holding back knowledge diffusion. In the profile below that would seem to be the most significant weakness.

Development Profile

Continue Using Regions

Countries or Regions India **Select Year** 2000

Select File: 0 - Working File, based on IFSBASE.RUN

	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					0.0998	
Years of Education	4.766	4.125	2.822	0.2272		0.1
Education Expenditure (Log)	4.086	3.844	2.03	0.1195		0.3
Life Expentancy	62.8	58.46	9.861	0.4402		0.1
Health Expenditure (Log)	1	2.571	1.444	-1.088		0.3
Social Capital					0.3138	
Freedom	11	8.716	4.624	0.4939		0
Governance Effectiveness (Linear)	2.37	1.849	0.4855	1.074		0.5
Governance Effectiveness (Log)	2.37	1.899	0.4855	0.9702		0.5
Corruption Perception	2.8	2.611	1.349	0.1404		0.2
Economic Freedom (Log)	6.328	5.85	2.663	0.1794		0.1
Physical Capital					-0.1661	
Road Ntwk/Land Area	10.1	2.053	6496	0.0012		0.0001
Kilowatt-hours per capita	357	741.2	2466	-0.1558		0
Telephones per 1000	37.52	58.12	83.23	-0.2475		0.6
Internet Percent Use	0.5433	2.253	9.746	-0.1754		0.025
Knowledge					-0.6643	
R&D Expenditures	0.146	0.18	0.1039	-0.3275		0.5
Economic Integration						0.2

And, finally, turning to China, the figure below suggests a pattern of strong social capital, notably government effectiveness, compared to typical patterns at its level of development, and similarly quite strong infrastructure/physical capital. In the human capital arena, it is interesting that both years of education and life expectancy are unusually high and make positive contributions, but expenditures on both education and health as portions of GDP are significantly below expected levels. This throws up a red flag with respect to human capital in future years. Knowledge creation benefits from higher than typical R&D levels, but suffered (in 2000) from lower than typical economic integration in spite of the tremendous growth in trade and FDI of the 1990s.

Development Profile

Continue Using Regions

Countries or Regions China **Select Year** 2000

Select File: 0 - Working File, based on IFSBASE.RUN

	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					-0.1947	
Years of Education	5.735	5.289	2.822	0.1581		0.1
Education Expenditure (Log)	2.183	4.157	2.03	-0.9726		0.3
Life Expectancy	70.26	63.11	9.861	0.7252		0.1
Health Expenditure (Log)	1.938	3.145	1.444	-0.8359		0.3
Social Capital					0.3353	
Freedom	3	7.649	4.624	-1.005		0
Governance Effectiveness (Linear)	2.68	1.996	0.4855	1.409		0.5
Governance Effectiveness (Log)	2.68	2.31	0.4855	0.763		0.5
Corruption Perception	3.4	2.933	1.349	0.3459		0.2
Economic Freedom (Log)	5.738	6.177	2.663	-0.1648		0.1
Physical Capital					0.2257	
Road Ntwk/Land Area	1.408	2.802	6496	-0.0002		0.0001
Kilowatt-hours per capita	827	1280	2466	-0.1839		0
Telephones per 1000	137.4	90.7	83.23	0.5612		0.6
Internet Percent Use	1.737	3.891	9.746	-0.2211		0.025
Knowledge					-0.2102	
R&D Expenditures	0.2173	0.1853	0.1039	0.3079		0.5
Economic Integration						0.2

The above profiles of countries and regions will certainly be improved as the productivity formulation in IFs continues to be refined. In general, however, it should be safe to say that the existing formulation already makes IFs a quite useful tool for clinical assessment of development performance and prospects and for forecasting economic productivity and growth. That was the purpose of this project.

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