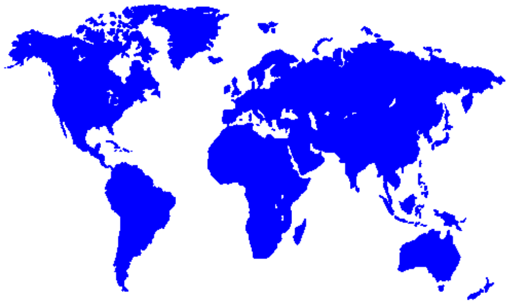

Long-Range Economic Modelling with International Futures (IFs)

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Abstract[1]

This presentation explores two questions surrounding long-range economic modeling: why we need it and what we need to achieve it. Long-term economic modeling is crucial for understanding issues of sustainability. A helpful metaphor for long-term economic modeling is that of a three-legged stool where each leg is crucial for the utility of the model. It is claimed that long-range economic modeling requires the following: an endogenous growth model, a model of market interaction that roughly chases equilibrium and the ability to embed this model within a nesting of other key global systems. In this paper, the intellectual traditions of these three legs are explored and the structure of the International Futures (IFs) economic model is outlined. A sampling of IFs forecast is then presented.

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[1] Thanks to Barry Hughes and Paul Lucas for support on this piece, as well as to Jack Donnelly for more broadly shaping my systems thinking. Any errors or omissions contained within this paper and presentation are mine alone.

1. Introduction: The Need for Long-term Economic Global Forecasting

Thinking analytically about the future is nothing new. Humans have engaged in this behavior with differing degrees of success for millennia. While the general act of forecasting is not unique, the methods and techniques that have been deployed, along with the time horizon, have shifted with improving technology and scholarship.

This improvement of technique has coincided with a qualitatively more intensely habituated planet. Human systems have become increasingly intense consumers of natural resources and impacts on environmental systems. Our problems, it can be assumed, are increasingly interconnected, dynamic and global.

While it has always been important to forecast the future, whether to determine when to harvest or where to invest, it is increasingly important to think systematically about the long-term future in the interest of global sustainability. Increasing population growth, emissions growth and usage of non-renewable forms of energy provide serious and challenging questions to policy makers and scholars. The ability of this generation to live without harming future generations is a challenging goal, and thinking towards that end is necessary.

The International Futures (IFs) model is one attempt to think systematically about the global, long-term future. The model does not attempt to predict what kind of world we will inhabit in the next 5, 10, 50 or 100 years, but rather presents different sets of scenarios based on the interaction between different decisive systems. This dynamic, non-linear interaction between systems provides a potentially helpful launching point to begin to thinking about long-term human choice in a complicated world.

One system within this modeling platform that is a key driver of other systems is the economic model. The modeling of growth and production drives other key systems within the broader system. Poverty alleviation is tied to increased productivity and proper distribution. Endogenous growth of technology leads to the potential for renewable energy sources to be increasingly exploited. Much of our ability to intervene in other systems is contingent on the level of material resources that we are able to exploit.

An integrated economic model embedded within a larger model can also reproduce market interactions and account for stocks and flows between economic actors. This kind of system can be used to highlight the trend away from industrialization and towards service-based economic production, or from a low-skilled work force to a higher-skilled labor pool. This accounting method can highlight important points of structural change within economic systems as they interact with other natural systems.

While the modeling of economic production and interaction is crucial for understanding a complex future of structural change, it is not sufficient. Endogenous growth must be further embedded within a nesting of other models that both enable and constrain production, that are pushed and pulled by the demands of the economy and that respond to a changing set of environmental resources.

This paper presents the IFs economic model within the nesting of other models within the IFs modeling platform. It firstly asks what is necessary to create a long-term economic forecast and traces out a taxonomy of these needs through time. The needs are three-fold, and can be thought of as representing three legs of a stool: the need to endogenize productivity, technology and human capital accumulation in a production function, the need to create a model that effectively chases equilibrium and the need to embed this forecast within other systems to produce a dynamic forecast that is not reductive, but additive. The next section explores the structure of the IFs economic model. The final section concludes, presents the result of some forecast results and explores options for further research.

2. Economic Modeling: A Theoretical Perspective

Introduction

The prerequisites and constraints of long-term global economic models requires a confluence of unique and specific features to produce results that reflect dynamics that are both endogenous and recursive. I argue that the main features required of these models to produce results that are of high quality and that reflect long-term trends can be, at a minimum, broken down into three distinct theoretical and practical ventures: the modeling of production, market interaction and the interaction of linkages to other issue-specific models. These three perspectives can be represented as three legs of a stool: when one leg is missing or inadequately developed, the utility of the stool is compromised and the quality of the results of the model is reduced.

We begin our development of a long-term, global economic model by exploring the long-term determinants of economic growth. A genealogy of thought is traced from earlier models of growth that attempted to conceptualize the relationship between labor and capital, through to the development of models of how the determinants of growth are transferred across time and space. We begin with the Harrod-Domar model of growth, moving to the very influential work of Cobb and Douglas. We augment this production function by separating capital into both physical and human capital, and giving both drivers of production distinct characteristics. We then add to the production function an endogenously derived technological factor that allows for increased productivity in the use of capital by labor. This more nuanced production function, what compromises the long-term determinants of economic growth, then must be explored across countries to account for how growth rates may or may not converge on system leaders.

The second leg of our economic model brings this supply side in contact with consumers and governments. This leg of our stool requires that we create a segregated market, in our case, dividing the market into firms, governments and households. This also requires that production is responsive to price signals. The linkages from the production function to the market place are not unidirectional: prices do come back and affect levels of technological improvement, human capital distribution and the level of productivity. Finally, this process is brought together and moved forward through modeling accounting practices, specifically the use of a Social Accounting Matrix (SAM)..

The final phase of long-term, global economic modeling requires that the relationships between variables of our earlier model become linked with other models representing aspects of the world that are not directly explored in our initial framing of production, consumption and market-place interaction. These forward linkages from the economic model to other models are also not unidirectional, and the relationship between various issue-specific models and our economic model blend across time as the dynamic effects of different systems are taken into account. This leg of our stool is both theoretically and practically the most complex section of our long-term economic model, and requires more documentation than this format allows.

What are the Long-Term Determinants of Growth?

Models of Growth

Many have written about the determinants of economic growth. From Smith to Ricardo to modern writers of pop-economic literature, authors have presented a variety of explanations for the drivers of increasing and sustainable output, and why these rates may differ across region. This body of literature, writ large, is at least as varied as are the purposes of its authors. In this section, we focus on those who have written more directly towards models that can be used and adapted for long-term economic growth studies.

Our study of the history of thought on the drivers of long-term economic growth tells a story of increasingly nuanced theoretical and applied models of growth that attempt to paint a more clear picture of how qualitatively different forms of capital and labor in order to increase output. The Harrod-Domar model is foundational to this story, and it is where we begin (Domar 1946; Harrod 1939). The basic assumptions of this model, as identified by Hahn and Mathews, are three-fold: an unchanging percentage of income is saved; the ratio of capital to labor in production is fixed; and labor is determined exogenously (FH Hahn and Matthews 1964, 783). These modelers are identified with exploring the role of capital accumulation in the process of production; the H-D approach relies heavily on the relationship between capital accumulation through savings and economic output.

While Harrod and Domar brought capital accumulation to bear in the production function, at its most basic, economic growth rests on an interaction between labour and capital. This was elucidated by Cobb and Douglas in their work exploring the methodological implications the determinants of production (1928). Their findings in this important article are not meant to be definitive, but rather illustrative: "It is the purpose of this paper...not to state results but to illustrate a method of attack" (1928, 156). Their method was to be used to determine the relative ratio of labor to capital in optimum production. The formula that they deployed also included an exogenously determined productivity, or technology variable.

The Cobb-Douglas production function remains a cornerstone of theories of growth and output. Though they wrote before either Harrod or Domar, Cobb and Douglas contained within them an emphasis on a methodology that is committed to measuring the relative importance of both labor and capital in output production. Additionally, this labor-capital formulation represents the theoretical and practical heart of a long-term model of economic growth and, in that sense, is broadly interesting. Pools of labor, interacting with pools of capital, contingent on a measure of technology, create output, and thus directly drive economic growth.

However, this formulation also only begins to scratch the surface of the complexity of the issue at hand. Without distinguishing what constitutes labor, what constitutes capital, and how to control for myriad intervening variables, it becomes difficult to apply the labor plus capital equals growth equation in a practical model. Additionally, there is a wide variety of other nuance that must be taken into account. How is technology and productivity determined in the model? Is capital broken down into different sectors, or qualified differently based on whether it is physical or human? Two what degree are savings and investments of consumers brought to bear on the growth model? These added complexities necessary for a robust model of economic growth were not fully lost on Cobb or Douglas. Their approach was an attempt to illustrate a method for measuring relative importance of capital and labor in the production process and not to exhaust the possibilities of economic growth theory.

The further exploration of the variety of determinants of economic growth most notably took place through the work of Solow (1956). Starting with a critique of the Harrod-Domar model, Solow took issue with what he saw to be overly deterministic assumptions, which caused the results of the model to be excessively rigid. "Were the magnitudes of the key parameters...to slip ever so slightly from dead center, the consequence would be either growing unemployment or prolonged inflation" (Solow 1956, 65). The assumption of this model was fixed proportions in production, thus the inability of substituting labor for capital in production. This created steady-states that Solow describes as resting on a "knife-edge". Any disturbance of this equilibrium will result in negative consequences of the economy within the model. Hahn and Mathews argue that it would be incorrect to assume that Harrod-Domar were not aware of this rigidity, but that they did not believe that it should be changed, as technology was exogenous in the model, the ratio of capital to labor could not change (FH Hahn and Matthews 1964, 789-90).

The neoclassical model that Solow promotes is one where this "knife-edge" can never exist, because there is substitutability in factors in production as well as constant returns to scale. "The system can adjust to any given rate of growth of the labor force, and eventually approach a state of steady proportional expansion" (Solow 1956, 73).

Jones describes the assumptions of the Solow model (1998). There is no international trade because there is only one good produced. Consumers save a percent of their income and consume another percent. Two equations are present: one for capital formation and another for production. There are diminishing returns on investment. The capital/labor ratio is determined by depreciation, investment and changes in the size of labor.

Mankiw, Romer and Weil explore the Solow model empirically and find that it is quite accurate, especially when capital is separated into physical and human (1992). Solow took savings and population growth rates as being exogenously determined, and applied them to a standard neoclassical production function. These two exogenous variables were used to determine different steady-states of an economy.

As per the trajectory of our story of economic growth, a variable taking into account technology had been included in production functions from Cobb-Douglas forward. However, it was the work of scholars coming later who pushed this concept further and incorporated it into the model in a more rigorous, endogenous way. For example, Romer expanded upon the Solow model to include the non-rivalrious notion of ideas and technological innovation as factors determining levels of economic growth (1990, 2005; 1994). He argues that the stock of human capital is the main determinant of economic growth, and that it is not sufficient to have a large population for growth to occur. Three premises are put forth in one of his most important pieces (PM Romer 1990): Firstly, technological changes are the foundation of economic growth. Secondly, these improvements in technology derive from rational actors responding to market signals. Thirdly, the way that costs of technological improvements are absorbed are unique: they are initially absorbed, and then do not require large investments to adopt. Technology is a non-rivalrous, partially excludable good. "The most interesting positive implication of the model is that an economy with a larger total stock of human capital will experience faster growth" (PM Romer 1990:99)

As an overview, Romer writes that endogenous growth theory departs from standard neoclassical theory because it does not see the growth of technology as being exogenously determined and imposed upon the model, but rather it understands economic growth as necessarily bringing about additional growth to the stock of technology, which thus alters levels of productivity. Eventually, Romer argues that growth models need to move towards models of imperfect competition.

While enodgenous technological production was useful in pushing growth models forward, another variable was being promoted by different scholars: human capital. The issue of human capital has been explored foundationally by Becker (1964) and Shultz (1963). Human capital formation can take place in at least two important ways. One of the earliest writers on the subject, Schultz (1963), drew a clear distinction between education and schooling. The former was an amalgamation of different qualities that meant to draw out potential from a person that lies latent within (1963:3). The later was seen through the lenses of a cost-benefit analysis: labor would incur the cost of going to school for the benefit of increased long-term output.

Lucas places the discussion of human capital formation and economic growth within the broader debate about economic growth (2000; 1988, 1990). Firstly, there is the standard neoclassical model that emphasizes physical capital accumulation and technological change. Secondly, there is a model that explores an investment in human capital accumulation through school attendance. Finally, there is a model of human capital development through learning-by-doing. The author finds that the first two models, the standard neoclassical model and the model of investment in human capital, both produce similar results that conform to data on the US. The third model, however, takes a step away from the first two models by not making human capital development a zero-sum game: this development can take place without extensive investments in education, and thus cuts in short term production. Lucas moves through each of these models in an attempt to build a model that adequately maps patterns of development. "A successful theory of economic development clearly needs, in the first place, mechanics that are consistent with sustained growth and with sustained diversity in income levels...But there is no one pattern of growth to which all economies conform, so a useful theory needs also to capture some forces for change in these patterns, and a mechanics that permits these forces to operate" (1988:41). The theory that the author finds useful for mapping these changes in patterns involves the incorporation of the learning-by-doing model described earlier on top of earlier neoclassical models and neoclassical models plus human capital.

Becker, Murphy and Tamura argue that different steady-states are achieved based on different levels of human capital accumulation. "As a result, societies with limited human capital choose large families and invest little in each member; those with abundant human capital do the opposite. This leads to two stable steady states. One has large families and little human capital; the other has small families and perhaps growing human and physical capital" (1990:12).

Nelson and Phelps argue that, as economies move from more routenized production environments for labor to more dynamic roles, the process of human capital formation produces increasingly large returns. ""We suggest that, in a technologically progressive or dynamic economy, production management is a function requiring adaptation to change and that the more educated a manager is, the quicker will he be to introduce new techniques of production. To put the hypothesis simply, educated people make good innovators, so that education speeds the process of technological diffusion" (1966:70).

Still further debates about the nature of economic growth focused on comparative growth rates. The "convergence" debate explored how technological transfer may or may not cause different countries to converge in economic growth rates and steady-states of the economy. Jones provides a helpful dissection of this debate (1997). Two strands of convergence literature emerge from this discussion. The first was started by the work of Abrimovitz (1986) and Baumol (1986) and focused specifically on rich country convergence and ignored global convergence. The second set of literature emanated from the scholarship of Barro (1991) and Mankiw, Romer and Weil (1992). This focused on global convergence.

Convergence occurs, from a neo-classical economic perspective, because countries with higher ratios of capital to labor have a more difficult time increasing the returns from an additional unit of capital, while poor countries have a greater return on increasing one unit of capital relative to labor. "The main element behind the convergence result in neoclassical growth models is diminishing returns to reproducible capital. Poor countries, with low ratios of capital to labor, have high marginal products of capital and thereby tend to grow at high rates. This tendency for low-income countries to grow at high rates is reinforced in extensions of the neoclassical models that allow for international mobility of capital and technology" (RJ Barro 1991:407)

Barro argues that the standard convergence argument is not fully supported with empirical evidence, and that it is not, in fact, the initial level of real GDP per capital that affects whether or not poor countries converge with rich countries, but it is rather the degree to which poor countries have invested in human capital that determines convergence rates (1991). "Although the simple correlation between per capita growth...and the initial...level of per capita GDP is close to zero, the correlation becomes substantially negative if measures of initial human capital...are held constant" (1991:438).

Romer argues that convergence may be happening, but not for the same reasons that the Cobb-Douglas formula posits (1994). Instead of a convergence towards similar levels of per capita income arising from decreasing returns on capital, Romer argues that some convergence phenomena occur because of knowledge spill-over effects which are heightened by capital mobility.

Some are concerned not with the degree to which countries converge to steady-states, but rather to how those different steady states will be distributed. Accounts of convergence show that global convergence takes place at about 2% per year. In a different article, Barro explored convergence within the United States and found there to be a convergence of poor states to rich states is about 2% (1991).

This growth can be towards different steady-states of an economy. Jones is curious as to the degree that these different steady states differ from one another (1997). The author finally argues that there is no reason that one should imagine that the US should remain as the country with the most output per worker.

Mankiw, Romer and Weil argue that the Solow model of growth and convergence is quite accurate when explored empirically, especially when capital is separated into both physical and human (1992). They argue, however, that different economies will reach different steady states, and that this was Solow's point, because of the determination of population growth and savings rate.

Abramovitz writes about catch-up phenomena related to economic growth specifically after WWII (1986). Writing about growth from the perspective of productivity growth rates, other countries enjoying the peace after 1945 were able to catch up with the level of US technological development because they were not forced to go through the process of early development. It is generally held by Abramovitz that countries with lower levels of productivity will catch up to those with higher levels, and that this is contingent on some degree of social capabilities which allow for this process of development and increased production to occur (1986:391)

Not all, however, believe that convergence in growth is a historical fact. In fact, Pritchett argues that the exact opposite, divergence, has been the most pressing historical fact. This author cites sets of data that are typically used to explain the phenomena of convergence and describes how they are faulty and misleading. "Whichever way the debate about whether there has been some 'conditional' convergence in the recent period is settled, the fact remains that one overwhelming feature of the period of modern economic growth is massive divergence of absolute and relative incomes across countries, a fact which must be grappled with in a fully satisfactory model of economic growth and development" (1995:37).

How do Markets Affect Growth?

"…the model represents a kind of 'lurching equilibrium'"

(Adelman and Sherman Robinson 1978:35).

The story related to the first leg of our stool, the production of economic output, was told in the previous section. In this section, we explore the question of how the first leg of our stool interacts with the second leg. In other words, how do the interactions of buyers and sellers affect the modeling of economic growth?

Bringing a growth model into contact with a market model with a long-term forecasting perspective produces a certain set of requirements. In the previous section on economic growth, the process of further elaboration and segmentation of the model was evident. Capital was broken down into both human and physical, productivity improvement could be seen as either endogenous technology production, investment in formal education or learning-by-doing. Additionally, the market model requires further deconstructing. For example, actors must be broken down into at least households and firms, and most plausibly into households, firms and governments. Actor behavior must be specified.

The modeling of market interaction is typically identified as taking place within Computable General Equilibrium models (CGE), and I will use that terminology. The story of modeling market interactions can be told as taking place on a continuum from abstract to applied (Sherman Robinson 1988, 891). Analytical models are those that orientate themselves towards exploring implications of economic theory and are rooted almost entirely in Walrasian notions of equilibrium, a concept that will be explored below. Applied models have a different goal: to use endogenously determined levels of equilibrium to model real-world situations with different degrees of complexity. The separation between analytical and applied models is not a strict binary, and distinct models can fall at different points along a continuum relative to the model's aspirations and needs.

The Adelman and Robinson model of Korea (1978) is widely regarded as the first CGE model[2]. This work modeled economic equilibrium within an economy using improved computing technology. While theories about economic equilibrium had existed for nearly a century (Léon Walras 1954), and while there had been much improvement in quantifying these equilibria (Arrow and Debreu 1954), this was the first time that they had been applied to a specific economic problem for a specific economic zone. Moving forward, CGEs became a cornerstone methodology for economic modeling and policy analysis[3].

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[2] Though this is not a universal recognition. Many see the work of Johansen as being the first model to deal with these issues formally, as it was a multi-sectoral model that attempted to take into consideration economic growth (1974)

[3] See Decaluwé (1988) for an overview of 73 CGE applications. See de Melo (1988) and MacLaren (2002) for an overview of CGE models applied to issues of trade policy. See Conrad (1999), Dellink (2005), Glomsrod et. al. (1992) and Bohringer and Welsch (2004) for CGE applications in the area of environmental policy. See Benjamin et. al. (1989), Vos (1998) and Bandara (1991) for CGE treatment of Dutch Disease. See Maldonado et. al. (Maldonado, Tourinho, and Valli 2007), Gelan (2002), Braber et. al. (1996), Xu (1996), Miller and Spencer (1977) and Bajo-Rubio and Gomez-Plana (2005) for a selection of country-based CGE analyses.

In their most abstract form, these models explore the interaction of buyers and sellers in a hypothetical market. These market actors are typically identified as either firms our households. These models highlight the observation that, in economies, "…everything depends on everything else" (Hertel et al. 2007:294). The interaction of these agents, i.e., the reliance of firms on households to consume goods and services and the reliance of households on firms for the production of these goods and services, leads to the establishment of price levels, eventually reaching a price that is optimal for all parties. An equilibrium price is reached where a re-computation of the interaction of buyers and sellers does not alter the price with successive iterations.

The establishment of an equilibrium resulting from the interactions of buyers and sellers in a market was famously explored by Léon Walras (1954). Walras constructed what can be considered to be the most basic economic system, one that consisted solely of producers and consumers, and that relied on assumptions of scarcity[4]. It was from this model that an equilibrium price could be established for traded goods. The results from the model would be market clearing behavior: all goods would be consumed at an ideal price for both consumers and producers. Market clearing behavior happens endogenously to the market, which is germane to our further discussion. This approach to theoretically modeling market interaction is seen by some to be one of the, "…crowning intellectual achievements of economics" (Hertel, Keeney, Ivanic, and L. Alan Winters 2007, 294).

Walras' theoretical market is useful for analysis and general conclusions about the nature of buying and selling in an unregulated manner. In addition, some realized that this abstract approach held untapped potential in that it could be made into a practical tool for specific analysis. Arrow and Debrew understood the importance of Walras' contribution to economic thought, but they felt that it lacked because, "[it] did not…give any conclusive arguments to show that the equations…have a solution" (1954:264). These authors explored the implications of this producer/consumer model by exploring mathematical solutions to market relationships that eventually came to an equilibrating price. The result of Arrow and Debrew's study was the establishment of, "…two theorems stating very general conditions under which a competitive equilibrium will exist" (Arrow and Debreu 1954:266). These theorems were the foundation for the further development of a tool that could seek equilibrium endogenously.

In order to build these mathematical relationships into a computable model of economic interactions, additional developments proved helpful, specifically, accounting tools were to prove quite useful. Leointiff (Leontief 1966) pioneered an accounting method involving Input-Output (I-O) matrices. I-O models track the inputs and outputs of goods and factors in different sectors of an economy. These accounting tables can become quite complex, and are very useful for demonstrating reliance amongst different sectors of the economy. While I-O models can stand on their own and provide a certain kind of

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[4] "Only useful things limited in quantity can be produced by industry and all things that industry produces are scarce…In fact we may be certain that industry does nothing but produce scarce things and that it endeavors to produce them all" (Léon Walras 1954:73).

analysis[5], they additionally form a theoretical foundation for CGEs. Rose (1995) offers a critique to CGE authors who do not recognize this lineage.

A further accounting method, the social accounting matrix (SAM), is also widely used to account for the interactions of different actors in an economy. SAM-like structures have existed for a very long time, and can be traced back as far as the French economist Quesnay and his development of the *tableau économique* (1766). The more recent deployment of a SAM-like structure was undertaken by Stone and Brown (1962). A SAM is, "…a comprehensive, economy wide data framework, typically representing the economy of a nation" (Lofgren, Harris, and S. Robinson 2002:3). For example, a SAM takes into consideration the current stocks and flows resulting from the interaction of buyers and sellers in a market place. These matrices are also used to track imports, exports, governmental redistribution, etc[6]. Additional work on accounting matrices has been conducted by Rob Vos who promotes the use of a World Accounting Matrix (WAM) (1988).

Adelman and Robinson are widely seen to be the first to combine the equilibrium seeking theory of Walras, the mathematical representations of Arrow and Debreu[7] and the I-O and SAM accounting techniques to create a computable general equilibrium (CGE) model (1978)[8]. Their model of the South Korean economy explored the implications of government policies on income distribution. Their model allowed for, "…the substitutability of factors and commodities, wage and price interactions, and the maintenance of various accounting constraints" (1978:19). However, what set their CGE approach apart from other global modeling methods is that they not only substituted production factors, but also allowed for changes to price and income to happen internal to the model (1978:20)[9].

This modeling technique endogenously sought equilibrium. The determination of equilibrium, in the case of Adelman and Robinson, that of prices and wages, is what has set CGE models apart from other models. The particular equilibrium sought by Adelman and Robinson also aligns nicely with the equilibrium that Walras sought in his early theoretical markets.

The endogenous determination of equilibrium, especially that of prices and wages, has been used widely by policy analysts and theorists to explore economies in great detail. A standard CGE approach to policy analysis assumes that there are two important actors in an economy, producers and consumers. These

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[5] See: (Rose and Miernyk 1989).

[6] For more information on SAMs, see (Defourny and Thorbecke 1984), (Graham Pyatt and Round 1979), (G Pyatt 1988) and (Graham Pyatt 1976).

[7] "Computable general equilibrium…models are simulations that combine the abstract general equilibrium structure formalized by Arrow and Debreu with realistic economic data to solve numerically for the levels of supply, demand and price that support equilibrium across a specified set of markets" (Wing 2004:1)

[8] Though there have been other attempts to combine these disparate works and themes theoretically and practically. See (Scarf and Hansen 1973) and (Johansen 1974).

[9] "Basically, what differentiates our model from other multisectoral models is that it solves endogenously for wages and prices in a multifactor, multiconsumer, multiproduct world in which firm and consumer behaviour is based on the optimization of separate objective functions" (Adelman and Sherman Robinson 1978:19)

actors interact by buying goods and factors, of which both have a share. These interactions are premised to take place under conditions of rational profit or utility maximization.

The two actors in the model, households and firms, are the producers and consumers in the previously discussed Walrasian economic theory. Households are assumed to maximize their own utility. Firms are assumed to maximize their profits. Devarajan, Lewis and Robinson created a "minimalist" CGE model that they call the 1-2-3 model (1990). "The model has three actors: a producer, a household, and the rest of the world" (S Devarajan, Lewis, and S Robinson 1990:627). The benefit of creating such a stripped-down model is the clarity that is provided in analysis: it is much simpler to see causal interaction in a simple model than in a large, complex model.

These producers and consumers interact by buying and selling goods and factors. In an economy, every good requires a factor for production. In a stripped-down CGE, every producer supplies only one good. The factors are owned by consumers. Thus both the consumer and producer, or the household and the firm, have incentive to engage in a market and exchange either their goods in order to determine prices or their factors in order to determine wages (Wing 2004) (Ginsburgh and Keyzer 1997).

Government can be the third actor that is imposed on the CGE model, which changes the efficiency of the interaction of households and firms. Governments essentially act as agents of redistribution in CGE formulation. This redistribution can occur to varying degrees. For example, Wing (2004) imposes tax distortions onto a minimalist CGE model to demonstrate a function of the model, though also cautions that the further one moves away from the simple CGE model, the more that it can become like a "black box".

It is also important to specify how actors engage one another within a market framework. Many CGE models make assumption about agent activity, such as utility and profit maximization. Conrad (1999) along with Shoven and Whalley (1992) use utility and profit maximization explicitly in their definitions of CGEs[1].

Some authors and modelers emphasize the market-clearing quality of economic models as being foundational in the creation of a CGEs. For example, Dellink points to three conditions that are required for the establishment of a CGE. Firstly, CGE models must satisfy the "zero profit condition" for firms, which is achieved when, "…under constant returns to scale the value of output has to equal the value of all inputs". Next, there is the "income condition": households can not increase their expenditures above income. Finally, there is the "market clearing condition", where, "For each good…total demand equals total supply. For the primary production factors, labour and capital, this means that total demand for these goods must be equal to the total amount available" (2005:17). The core of these models is, "…that prices of all goods are determined within the model such that all the conditions stated above are satisfied simultaneously…for every demand there is a supply" (2005:18).

A thorough account of how standard CGE models are structured is provided by Adelman and Robinson (1988). These authors posit a rubric of four criterion used to identify CGE models. Firstly, these models must specify the actors that the model's economy will take into consideration. These are typically limited to households, firms, governments and the rest of the world. Secondly, the model must describe the behavior of the different actors operating within the model. Many times this is defined as profit maximization for firms and utility maximization for households. Thirdly, the "nature of market interactions" should be specified. For example, is there a competitive market for both goods and labor? Finally, equilibrium must be found for each endogenous variable. This is typically achieved by determining a market-clearing price (Adelman and Sherman Robinson 1978).

Up to this point, it is relatively clear what composes a CGE model. However, the models discussed earlier do not fully encompass the breadth of available CGE platforms. At the beginning of this section of the article, the distinction between analytical and applied models was highlighted (Sherman Robinson 1988:892). The models so far discussed in this section have fallen more closely to analytical models on the continuum between analytical and applied.

In their most absolute form, analytical models are used to test out neo-classical economic theory assumptions about the interaction of producers and consumers in a pure market setting (S Devarajan, Lewis, and S Robinson 1990). These models are more clearly theoretically in their approach. In many cases, these models explore the implications of the addition of a third actor in the economic system: government acting as a redistributive agent through the mechanism of taxes (Wing 2004).

While these ideal-type models are useful for certain purposes, specifically those of economic theorists of the neo-classical tradition, an economic model that more broadly and empirically accurately can emulate modern economic interactions is desired in order to instruct policy decisions and analysis[10]. These models began to change the structure of interaction that occurred within a pure Walrasian equilibrium seeking model. Applied CGE models represent a distinct grouping of CGE models that attempts to be more empirically accurate in their analysis of the nuanced nature of modern economic interactions. These models problematize every aspect of the analytical CGE models, except for the endogenous determination of equilibrium. There is typically a gap between theorists who use analytical and applied CGE models[11].

One example of a well known applied CGE model, or AGE model[12], is the Worldscan model. "It builds upon neoclassical theory, has strong micro-foundations and explicitly determines simultaneous equilibrium on a large number of markets" (2-3). This model attempts to explore global economic interactions focusing not on linear development, but rather on structural change and transition. This model falls more closely to the applied CGE models because it is explicitly attempting to replicate global economic interaction and not explore theoretical constructions of hypothetical markets.

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[10] Shoven and Whalley: (1992) "Choice of the level of aggregation for an applied model is one of the more difficult design issues that any prospective modeler must confront. On the one hand, there is the natural desire to make the model as detailed as possible in the belief that this will increase its realism. On the other hand, more detail is not always beneficial; much of it may prove superfluous to the issues at hand: (100).

[11] Ginsburgh and Keyzer (1997) can be seen as partially addressing that gap, though they have a different gap they are clearly interested in: between modellers and users.

[12] AGE = applied general equilibrium

Dervis et al. (1982) trace out different models of economic development, specifically with an eye towards bridging the gap between reality and economic theory. The claim is that much of economic theory provides helpful insights on how an economy should function, but that, in reality, most economies are mixed economies. It becomes important to model the mixed nature of these economies. In their discussion of the different models explored in their work, the authors.

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> *The simple model developed in the early sections of the chapter was extremely Walrasian and neoclassical in spirit. With the exception of taxes on factor incomes and a brief allusion to fixed wages for certain labor categories, there was essentially no difference between the technologically feasible production possibility set and the resulting transformation set reflecting market behavior and institutional characteristics of the economy. All markets cleared. Applied models, however, although close in spirit to the Walrasian construct, can be characterized as reflecting a "constrained" general equilibrium. (Dervis, De Melo, and Sherman Robinson 1982:180)*

An additional piece by Gibson and Seventer (2000) compares two differently structured economic models relating to South Africa, one structuralist, or more applied, and the other neoclassical, or more analytical. Though the two models are not necessarily standardized to one another, a clear criticism of their work, they still find, not entirely surprisingly, that the structuralist model provides insight into a more complex, messy set of economic variables that affect economic production and the neoclassical model provides results that more clearly align with traditional neoclassical assumptions. This is one rare piece that explicitly examines two differently structured models, one applied and another analytical, to explore their distinct implications.

This may involve fixing prices in, for example, wages and/or exchange rates.

A final form of equilibrium that can be sought by these models is a macro-level equilibrium. Examples of this equilibrium are of levels of savings and investment, imports and exports or government spending and revenue (Sherman Robinson 1988:914). This form of equilibrium sought is grounded in Keynsian economic theory and can be most clearly seen in Taylor's account of structuralist CGEs (1990).

The continuum moving from analytical to applied does not, however, fully highlight the breadth of decisions that must be made on the part of modelers. Additional assumptions must be made in order to tailor model to its specific goals. For example, assumptions about actors must be explored by modelers. Firms and households are the actors typically represented in analytical models. Governments, among other potential actors, are added in more applied models. Characteristics about the behavior of actors must also be assumed. In analytical Walrasian models, this typically is represented by making actors price takers. This assumption is relaxed in more applied models as well. In addition to these assumptions, models must also find rules to close their calculations. These are identified by Robinson (1988) to be “equilibrium conditions”.

What makes both applied and analytical models, as stated before, both CGEs is that they both endogenously determine equilibrium[1]. Up to this point, the only discussion of equilibrium revolved around the interaction of firms and households in a market. This was a standard neoclassical equilibrium of prices and wages. This, however, is not the only kind of equilibrium that can be sought by modellers, and models that attempt to more closely replicate reality may seek equilibrium, or model closure, in different places.

Models that seek equilibrium, or model closure, that is not strictly neoclassical and Walrasian in nature identified as having greater degrees of structure. Robinson divides these structuralist models into three groups[1]: elasticity structuralists, micro structuralist and macro structuralists (1988). Therefore, in total, there are four kinds of equilibrium that can be endogenously determined, when standard neoclassical equilibrium is included, though there is a dizzyingly complex degree of variance in and among these modelling approaches.

Firstly, there is the standard, neo-classical equilibrium assumption previously outlined. Building towards our second equilibrium are “neoclassical structuralist” models (1988:914). These models utililize the endogenous equilibrium of prices and wages of the neoclassical models but argue, “…that there are important imperfect or incomplete markets, especially for factors of production and foreign exchange, in which prices do not respond to market forces” (1988:914).

This leads to more distorted market activities, and elasticity structuralist models. These models seek equilibrium that is responsive to a varying degree of substitution constraints imposed on the model. The equilibrium sought is still neoclassical, thought it is achieved after having been “distorted” by various hindrances to factor and good substitution. Prices are still the only signal moving the model towards closure.

Thirdly, there are micro level equilibriums that can be established in places that do not work “properly”. These models acknowledge that many markets simply do not work as they do in theory and thus allow markets to underwhelmingly meet the needs of producer and consumer: “…there are assumed to be restrictions on factor mobility, rigid prices, rationing, and neoclassical disequilibrium in one or more important markets” (Sherman Robinson 1988:914).

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This review claims that a wide variety of equilibrium can be sought by CGE models to varying degrees depending on the purposes of the model. This may, at first, seem like a severe departure from the theoretical approaches promoted by Walras at the end of the 19th century. However, Walras understood that actual economic interactions do not happen in a theoretical market involving only producers and consumers. Walras claimed that the interaction of producers and consumers is complex, and relies on new information being constantly revaluated by those in the market.

This pure economic system was understood by Walras to be an ideal-type. In his text, he promotes the idea that the equilibrium sought by the market can never actually be achieved, as the requirements for the economic system are not pragmatic; it is no coincidence that the title of his tome is Elements of Pure Economics. When consumers determine their indifference curve relative to a product, and the product is made and shipped, that same indifference curve is bound to change in one way or another. Extrapolate this simple example between one producer, one consumer and one product to the actual interaction of individuals in a market of infinite goods, and a market emerges that will never situate itself in a fully clearing equilibrium. Instead, "…the market has no other way of approaching equilibrium except by groping, and, before the goal is reached, it has to renew its efforts and start over again…" (Walras, 1954:380).

However, though the practical achievement of market clearing equilibrium was understood to be unattainable, even by Walras, the model did provide for a helpful tool for those exploring the implication of different policy interventions in an ideal-type market. These models initially imposed outside regimes, like taxes and tariffs, in order to model how this would affect the interaction of consumer and producer.

It may be instructive to situate Walras' text on pure economics within his life's work. Walras' economic works can be placed on a continuum moving from purely theoretical, what we will later call analytic models, to applied models. For example, van Daal situates Elements of Pure Economics within the purely theoretical camp: it provides an account of the state of exchange in nature (van Daal 2006:55).

Walras followed this ideal-type text with one that explored the pure economy in its interaction with society; it was a blend of pure theory and applied theory (1936). A third move on the part of Walras was towards a more applied economic text in his Studies of Applied Political Economy (1898).

By the end of Walras' first text, he has moved away from some initial, ideal-type assumptions to highlight the constantly evolving nature of market interactions. This complex, iterative process of interaction between actors produces a market that, "…has no other way of approaching equilibrium except by groping" (1954:380). This equilibrium chasing behavior is known as Walrasian *tâtonnement*.

Finishing the Model:

The full implications of the third leg of the stool are quite large. Linking an economic model with other systems requires detailed arguments and documentation about the implication of all of the connections. That is simply not possible in this paper. The IFs project more generally addresses this question, not specifically focused on the economic model, but through exploratory and analytical work from the perspectives of different systems within the broader, global system.

This section will very briefly explore the kinds of global, integrated thinking that have taken place historically. A further elaboration of this project would involve creating a taxonomy of different global models and their distinct methodologies for embedding the economic system dynamically within other systems.

A standard definition of sustainability refers to the ability to meet the needs of the present generation without compromising the ability of future generations to meet their needs (Brundtland 1987). The definition captures a crucial piece of long-range planning: decisions must be taken using the widest possible margin of future implications possible. Goldin and Winters narrow the definition of sustainability vis-a-vis economic growth by stating that it refers to, "...an economy in which future growth is not compromised by that of the present" (1995).

Long-term economic growth must be explored in relation to other global systems in order to understand issues of long-term sustainability and development. Because economic growth does not actually occur within a closed system that is isolated from environmental effects, writ-large, the IFs economic model must be nested within a broader set of models. This step represents the third leg of the stool, with growth theory and market theory being the first two legs.

Long-term thinking and global modeling focused on integrating systems in order to produce scenarios that explore issues of sustainability has taken place for some time now. Malthus most famously explored the relationship between population growth and food production, producing an argument that human development was ultimately constrained by the carrying capacity of the globe. This is one early form of thinking about global integrated systems and their relationship with future potential human developments.

In the early 1970s a more rigorous, quantitative model was produced in a broadly popular book called Limits to Growth (DH Meadows et al. 1972). This book utilized scenarios produced by the World3 model that explored the implications of decreasing natural resources on expanding populations. It provided a somewhat alarmist account of a future dystopia if these resource concerns were not addressed through policy intervention and life-style change.

In the early 1990s, a second version of this book was released (DH Meadows, DL Meadows, and Randers 1992). Beyond the Limits provided an account of a global society that had already overshot the carrying capacity of the globe's resources. The implications of this were explored, and options were provided to mitigate the negative impact of these oncoming constraints. Again, a third volume of this same type was produced that revisited the implications of a society that has overshot the earth's resource carrying capacity (DH Meadows, D Meadows, and Randers 2004).

These volumes brought global, integrated sustainability models to the forefront of discussions of the relationship between economic growth, environment and resources and what steps governments could take to intervene on behalf of long-term sustainable development. While the policy prescriptions that emanated from these reports have not been universally accepted, the methodology deployed attempted to dynamically link systems of economic growth, population growth, energy constraints to think about the long-term implications of human action on earth. These reports began the process of effectively stretching the forecasting capacity of humans.

While the authors of Limits to Growth are one of the earliest attempts to create a global integrated model, many have followed. Most notably, the Netherlands Environmental Assessment Agency has explored models of globally integrated systems for some time. They identify at least 12 different Integrated Assessment (IA) models that have developed since the early 1990s (Hilderink and P. Lucas 2008, 16). These models all attempt to bring together the complex set of dynamic systems thinking required to approach questions of global sustainability.

The particular model that they have been most recently created is called the Globally Integrated Sustainability MOdel (GISMO). The GISMO model has taken pieces of other IA models and combined them. These pieces include the IFs model, and especially the IFs economic model. These different modeling projects are brought together to understand and explore three goals: issues surrounding quality of life; sustainability writ-large; and points of policy leverage (Hilderink and P. Lucas 2008, 23).

This work will clearly continue into the future. The human need for relevant thinking tools about the global future will not abate. Further developing this third leg of the stool seems to be currently the most relevant area of focus for research, application and analysis.

Bringing it Together

The pieces of long-term economic modeling have been laid out and the stage is set to bring them together. The previous section highlighted three distinct trends that were required to produce these long-range forecasts of economic systems. Firstly, the model must take into account endogenous growth of technology, productivity and human capital through a standard production function. Secondly, actors must be distinguished and market-type interaction must be established that is equilibrium seeking. This also creates the opportunity to create an accounting framework through the SAM. Finally, this model must be embedded within a series of other important systems. This dynamic linking is what creates phenomena within the model that can be used and manipulated as a tool to help further our thinking about our collective, long-term future.

3. The International Futures (IFs) Economic Model

Explaining the structure and linkages of a comprehensive economic model that is embedded within a broader model designed to explore global change to the end of the century can be accomplished via a variety of approaches. It is possible to focus on different structural relationships within the model. Some IFs literature explores the implications of the structure of agent-class interactions, markets for goods and services and financial flow interactions to develop the story of the economic modelling approach (Hughes 2007). Other explorations of the model's structure could take the form of the methods of accounting for the development of various stocks and flows. The Social Accounting Matrix and the Input-Output matrix, both explored earlier in this paper, can be used as a medium for this development. Finally, it would be also compelling to develop an account of the economic model of IFs by exploring how it is positioned within the broader integrated modelling platform (Hughes, Hossain, and Irfan 2007).

This section explores the IFs economic model from the perspective of the literature developed in the previous three sections. This story is an account that attempts to highlight how the IFs economic model developed theoretically along the lines of previous developments within approaches to modelling economic interaction. This account of the model will explore how distinct building blocks developed by various theorists can be seen within the IFs model, starting with models of growth, moving to models of market interaction and then exploring the economic model within the broader integrated modelling platform.

Economic Growth in IFs

The variables discussed in the earlier section on economic growth represent the core considerations of the IFs economic model in determining production. The insights provided by, most specifically, the Cobb-Douglas production function, with a modified technology variable, represent the onus of the creation of output. Productivity are both effected through the endogenous growth of human capital and technology, insights provided by authors such as Solow, Romer and Lucas. This domestic model of production varies across national boundaries, and IFs accounts for relatively different growth patterns emerging in different countries through a convergence factor to the global productivity leader.

A crucial foundation for any long-term model of the global economy is an account of capital accumulation by sector. The IFs model separates capital into agriculture, energy, material inventories, manufacturing inventories, service inventories and information communication technology. The levels of capital stock are determined through endogenous accounts of inventory and savings levels, a feature that will be discussed in the following section on the IFs Market Model. Labor is accounted for in IFs through an endogenous calculation of population growth by age and sex cohorts through the demographic model[13].

The Value Added (VADD) variable is crucial for understanding how labor and capital interact in sectors to affect output. The capital stock, which depreciates at an annual rate and is eventually augmented

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[13] See www.ifs.du.edu/reports.aspx for more information on this IFs model.

through investment, interacts with labor, which, as noted earlier, in total is determined through the demographic model and is divided sectorally by demand, or Capacity Utilization (CAPUT), in order to produce VADD. The VADD variable drives total output (GDP and ZS).

However, the Cobb-Douglas production function, as noted in our earlier literature review, does not adequately take into consideration technology improvements and endogenous growth. Production levels must be augmented depending on different levels of human capital development and technology improvement. This is accomplished through a variety of levers in IFs.

Productivity in IFs is a function of the quality of capital interacting with levels of technology. The quality of social, human and physical capital all directly affect productivity and output in IFs. For human capital, its quality is determined by levels of education and health. Human Capital Investment (GDS), which is derived from levels of overall output and which is variable depending on things such as governmental investment in education and R&D, directly affects the level of worker productivity. For social capital, its quality is determined through measures of freedom and governance. Physical capital quality is derived from the availability of crucial drivers of growth, such as energy, for productivity.

Technological improvement in IFs also is a variable in determining productivity. This variable is driven partially through government investment in R&D. This investment theorised to promote knowledge diffusion through such factors as learning-by-doing, explored earlier. One way that this driver of productivity can be seen in IFs is through the number of networked people (NUMNWP).

As the IFs growth model begins to take a more coherent shape domestically, distinct growth patterns across states must also be accounted for. This is accomplished through the multifactor productivity growth rate (MFPRATE) for the system leader (a compilation of the leader's technological and knowledge creation) and an ability for other countries with lower multifactor productivity rates to converge. The convergence rates for different countries or regions are not uniform, and can be altered and affected through scenario development. The approach behind convergence, as discussed earlier, is that countries who have lower levels of production will more easily catch up to countries with higher levels of production than those countries with higher levels of production will be able to develop new technology.

At this point in the explication of the production model, we have reached a certain kind of impasse. We now have to bring the economic model back around and determine how initial levels of sectoral capital are determined. We also have to be able to account for changing levels of governmental investment in R&D in order to bring about changes in the production of technology and capital quality improvement. This involves an accounting system for the establishment of different actors within the economy as well as the determination of behavioral constraints for those actors as they respond to price signals in a market.

Embedding Growth within the Market:

As noted earlier, IFs divides capital into six sectors, and changes in the level of capital accumulation in each of these sectors is fully determined by the market interaction of households, firms and governments in an applied CGE model. The economic model equilibrates, but not fully, thus capturing the "groping equilibrium" highlighted earlier in this paper. This separation of the model into different actors interacting with a variety of different types of capital requires the imposition of a Social Accounting Matrix upon the model.

Changes in price by sector determine the relative quantity of demand and supply for the different types of capital. This changes their levels of production, and the sectoral composition of the economy as a whole. However, while the price mechanism attempts to endogenously correct for different levels of supply and demand for different forms of capital, these markets do not clear year to year. Sectoral capital stocks, represented as inventories, are used to keep a slight imbalance within the model from time period to time period. In this sense, IFs clearly represents an applied equilibrium seeking model.

Changes in price are represented through three separate changes. Firstly, the change in price of domestic demand is taken into consideration. This demand is a function of household consumption and savings patterns. Secondly, international trade changes the relative price for different sectors of capital. Thirdly, the price responds to changes in the levels of inventories, either attempting to bring these levels back in line with demand.

The different actors represented in the IFs market model are households, firms and governments.

The governments gather revenues through taxing both households and firms. In this model, this is represented as growing with growth in GDP per capita. Tax revenues are determined differently for both households and firms. Government expenditures are represented as pension payments and welfare payments. Government consumption is represented as expenditures on military, education, health, R&D and foreign aid.

Households are divided into skilled and unskilled, representing a trend towards the employment of an increasing ratio of skilled to unskilled labor over time. Additionally, consumption rates differ between skilled and unskilled households. Consumption is determined by multiplying income with a consumption ratio (CRA), as it is noted that household consumption rates as a percentage of GDP decrease as GDP per capita increases. What is not consumed or taxed is saved.

Firms invest based on expected GDP (GDPPOT) multiplied by an investment rate (IRA). This function produces the gross capital formation stock (IGCP). This core stock of capital can be varied through changes to interest rates, as well as changes in the stock of savings.

Now that each actor in the economy has been taken account of, it is possible to nest the economic model within the broader groupings of IFs models.

Nesting the Economy within other Systems

Exhausting the full range of linkages between the economic model and other models in IFs will not be accomplished in this paper. However, some of the more important linkages will be highlighted, along with the general structure of the relations between different models within the modeling platform.

Figure 1 represents literature taken from the IFs website (International Futures (IFs)). It represents a relatively recent update of the interaction between different important systems within the modeling platform. Notice that the economic system is linked with capital inputs from energy and agriculture, as well as labor inputs through population and health.

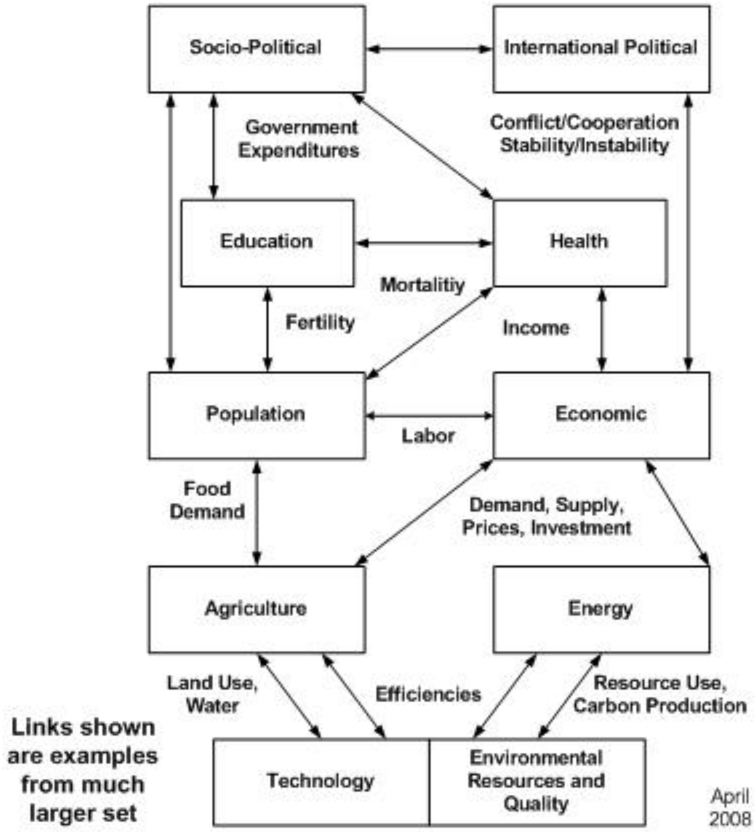

Figure 1: (International Futures (IFs))

The Help System of the software can help users understand the exact linkages between these systems. Visit the program's site online to download the software for free.

Through these linkages, it becomes possible to explore the implications of economic growth on other sectors of the global system. In the following section, we explore some of the implications for long-term environmental and energy production that emerge from these connections.

4. Forecasts from IFs

The point of this section of the paper is to provide the reader with an idea of the kinds of forecasts that are produced by IFs. The model is designed to produce different scenarios for analysis where key parameters have been altered to produce distinct futures. This kind of scenario analysis is a useful thinking tool about our collective future.

The forecasts used in the following sections are from the United Nations Environmental Project GEO 4, of which IFs was a crucial participant. The forecasts highlight the different implications of an integrated assessment model of global development.

IFs has been used by a wide variety of institutions to aid in policy decision making. Most notably, it has been integral in forecasting scenarios for the UNEP GEO 4 project (Programme 2007), the TERRA project (Stanford-Smith and Chiozza 2001), the NIC 2020 project (United States National Intelligence Council 2004), the NIC 2025 (United States National Intelligence Council 2008) project and currently the European Commission DG INFSO. An example of some of the forecasts used for those projects is provided below.

Each of the four scenarios, Markets, Policy, Security and Sustainability are fully annotated through the IFs Help System. Figure 2 shows global population forecast out to 2100. The different parameter changes affect where and when peak population will be reached.

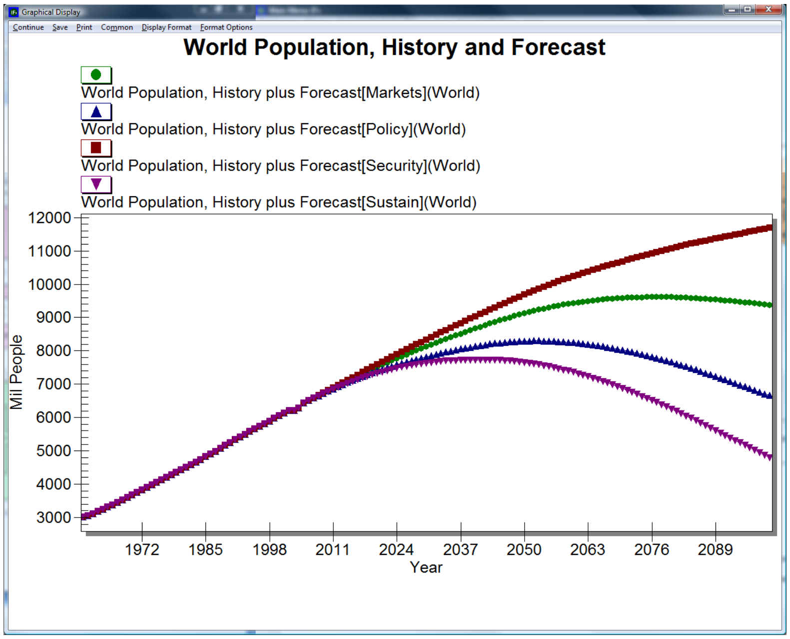

Figure 2: IFs World Population 1960-2100 for four UNEP scenarios

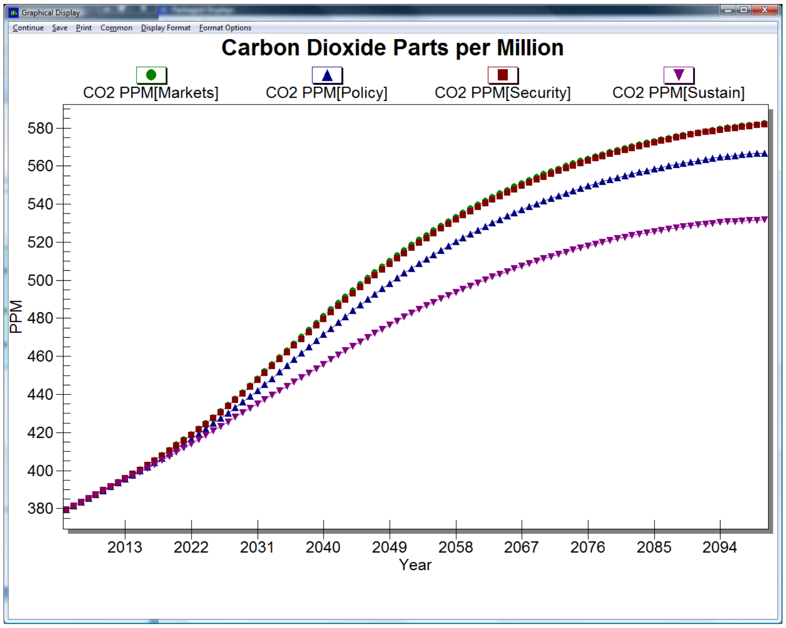

Figure 3: Carbon Dioxide in four UNEP Scenarios

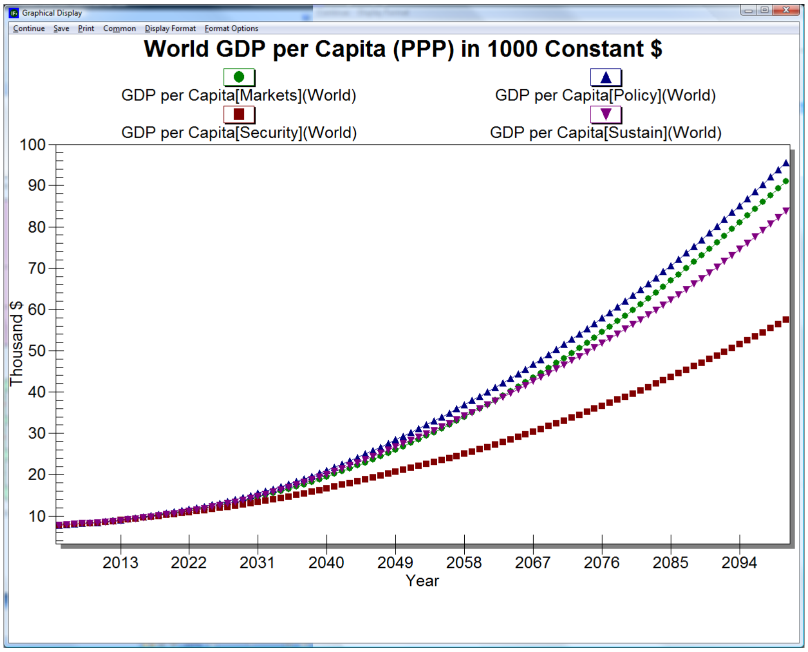

Figure 4: World GDP Per Capita at Purchasing Power Parity for four UNEP Scenarios

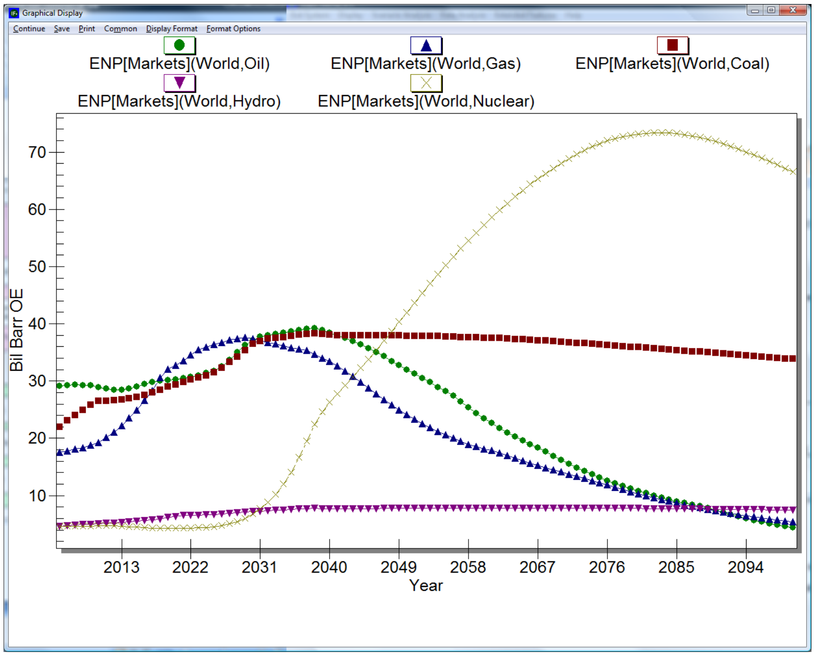

Figure 5: World Energy Production for the Markets UNEP Scenario missing Renewables

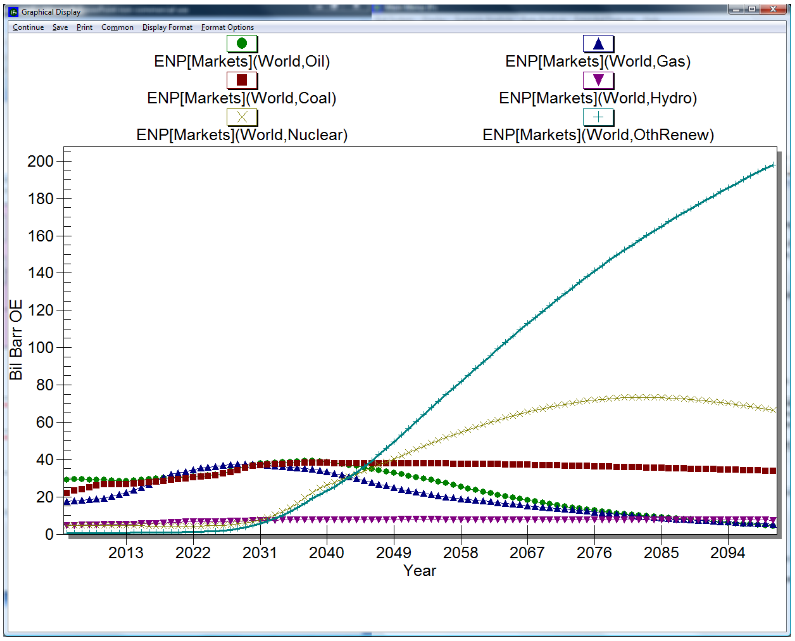

Figure 6: World Energy Production for Markets UNEP Scenario all production included

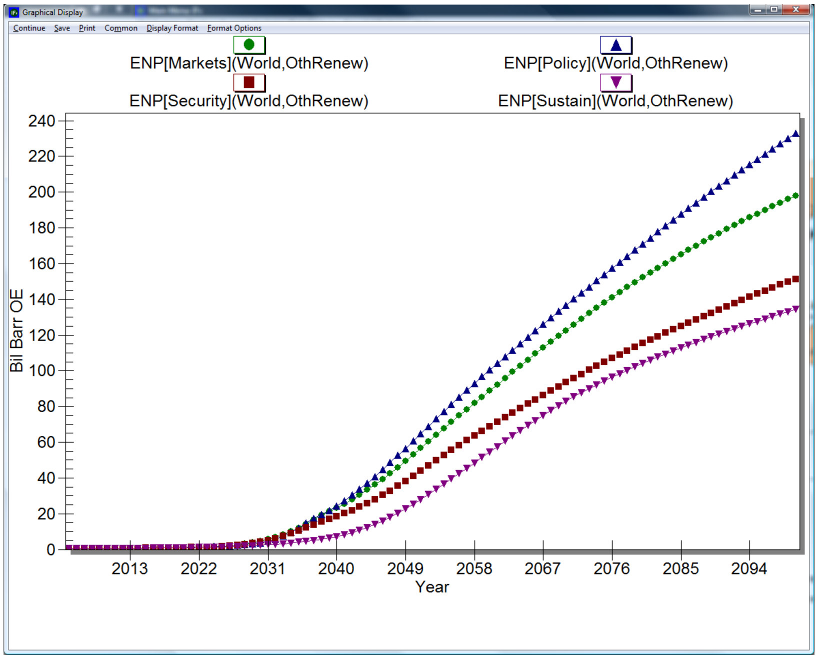

Figure 7: Renewable Energy Production for four UNEP Scenarios

5. Conclusion and Next Steps

The final sections of this paper represent a stage in a process and are not meant to be definitive scholarship. The following steps in the evaluation of long-term economic models requires that a comparative analysis of different modeling programs be conducted. This should focus on the different qualities of output based on the three legged stool method proposed earlier in this paper. The goal of this project should be finding ways to better conceptualize human thinking about and interactions with global systems.

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