Reflections on Long-Term Projections of Minerals and Suggestions for a Way Forward

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This article is an extension of two recent follow-up studies on long-term global projections completed a quarter century ago. It focuses on my experiences in global modeling and projections of mineral resources, specifically highlighting the principal determinants of demand for fuel- and non-fuel minerals. In addition, I provide some suggestions for a way forward to improve the usefulness of long-term modeling for framing the questions and analyzing the alternative feasible solutions for problems in the public policy debate.

INTRODUCTION

It is rare in the highly speculative science (art?) of long-term forecasting to revisit work carried out more than a quarter century ago. Too often, lamentably, the reason is all too obvious: after the passage of 25 years the incapacity, infirmity or death of the modeler intrudes. Absent this, invariably, there is usually a strong desire by the modeler to disassociate himself from, or even to try to disavow, the dust-accumulating study in order to avoid sullying a growing and otherwise unblemished professional reputation since committing those egregious “errors of youth”, i.e., those long-forgotten and discredited projections that he had hoped would never again see the light of day. However, for me, this was not an option. First, I am very much alive and well, and, second, being “thick-skinned”, it is not my nature to “cut and run”!

This article is an extension of two studies completed over the last three years (Sohn, 2005; Sohn, 2007) that revisited global long-term projections of fuel and non-fuel minerals made 25 years ago (Leontief and Sohn, 1982; Leontief et al, 1983). The centerpiece of this article is to share my experiences of long-term modeling with those currently engaged in making projections with a 25-50 year time-frame, and, in light of these experiences, to provide some insights and guidance towards improving the usefulness of long-term models despite the palpable uncertainties naturally embedded in a time frame that extends so far into the future.

The main focus of this article is not so much on reporting the differences – or why there were differences – between the projected and observed values of global minerals consumption as it is on assessing the key variables that drive minerals demand with a view towards improving the specifications of, and adjustments to, these variables over the projection interval. Practitioners of global long-term modeling and forecasting will agree that, irrespective of the modeling technique used, many of the key variables that drive fuel- and non-fuel-minerals demand, i.e., population and income growth, living standards, technological advance, and regulatory and political change, play the same critical role in determining the demand for most other goods and services that require long-term forecasts such as food, water, sewage, and major transport and environmental infrastructure, because of the extensive lead-time that is required to bring these projects forward from "proposal" to "ribbon-cutting". For example, the current public policy debate over global warming and the role of fossil fuels in causing global warming requires assumptions – however crude – regarding these key determinants of economic activity that extend out more than fifty years (Jaccard, 2005; Stern, 2007). Readers interested in the differences between the projected and observed values in these follow-up studies – and more importantly, the reason(s) for these differences – are referred to (Sohn, 2005 and Sohn, 2007).

Even though some readers of this journal are actively engaged in forecasting -- though probably in forecasting over the short-to-medium term of one to five years -- a few remarks are in order regarding some of the perils and pitfalls of engaging in long-term projections that extend out 20 or more years. Put simply, the margin for error regarding the end-year values of the key determinants of long-term projections is considerably greater than those for short-term forecasts because, in part, of the long compounding period. Also, it is important to note at the outset that projection "errors" at the country or regional level may not be adverse for the accuracy of the projections on a global level, a phenomenon referred to as "compensating errors" by Hans Landsberg, one of the pioneers of long-term forecasting of resources (Landsberg, 1985).

For example, even though the global long-term projections made in the early 1980s for the year 2000 would not capture the effects resulting from the collapse and eventual dissolution of the Soviet Union in the early 1990s, equally they would not capture the more than two decade run of robust economic growth of the Chinese economy. Together, these two recent extraordinary events could be a "wash" as far as global levels of minerals consumption are concerned but not, obviously, at the regional or country level.

In addition to these far-reaching political and economic realignments, as I will argue below, long-term models and their projections – as opposed to short- and medium-term forecasts – are also extremely sensitive to major technological and regulatory changes that were obviously unanticipated at the time the projections were made. For example, regulations that were adopted after the projections were made that restricted the use of mercury because of its proven toxicity, and which were phased-in over a decade or more, produced very large differences between the terminal year's observed and projected levels of mercury consumption.

On the other hand, as I will also argue below, because of the long time horizon, if the model is properly maintained, adjustments can be made in the intervening period as changes in the above mentioned variables and parameters are discerned, evaluated, and finally, incorporated into the model, triggering revisions – upwards or downwards – to the terminal year projected values.

Section one of the article briefly describes the justification for making projections--- with an example from the minerals sector -- that could extend out half-a-century as opposed to more conventional forecasting periods of 1-5 years. Section 2 provides an overview of the global model that was used 25 years ago for these long-term projections, along with a very brief summary of the "accuracy" of the global minerals projections versus the observed data for the year 2000. Section 3, with a view towards improving the modeling technique, highlights the principal determinants of demand and considers some of the current "red hot" issues in the national and global public policy debate that require the "long view". The last section of the article is concerned with some remarks that, in light of the experiences discussed above and the remarkable advances over the last three decades in computing and information technology, I believe can help to improve modeling (and perhaps the accuracy of the projections) over a relatively long time interval.

THE NEED FOR LONG-TERM PROJECTIONS: THE CASE OF MINERAL RESOURCES

Non-fuel mineral resources are the essential "building blocks" – the DNA – and fuel minerals are the energy source – the mitochondria – of "living standards" in a modern economy. Not only is the extensive array of consumer and capital goods either composed of metals or other materials that use energy resources in their production and consumption, but mineral resources are also extensively used in the provision of services – the largest (and still growing) component in total consumer expenditures -- albeit, in a more indirect way. While in advanced market economies the private sector is responsible for coordinating the secure, affordable and timely deliveries of a nation's resource requirements, because the physical endowments, mining capacities and the processing activities are increasingly based in countries different from those which are the principal consumers of mineral resources, even brief disruptions in their supply – the result of transport glitches, natural disasters, industrial disputes and strikes, terrorism, adverse weather conditions, political unrest, and wars – can have profound consequences for the performance of the national economy.

For example, the brief disruption in contracted supplies of Russian natural gas to Western Europe in January 2006 after the failure by Ukraine and Russia to reach an agreement on prices and transit fees and the temporary halt of Russian oil exports passing through Belarus in January 2007 both triggered European angst regarding their energy supply security. In order to manage this risk, negotiations were accelerated to find and lock-in alternative, i.e., non-Russian, sources of energy supplies for the next 25 years. The Russians, in turn, in order to manage their own risk exposure – energy-demand security – threatened to begin diversifying their customer base in order to ensure that their future sales, output levels, and capacities are in alignment, and that planned export revenue targets will be reached.

Consequently, national and local governments play a critical role in ensuring that resource supply chains are up and running in a seamless and timely way. Resource infrastructure must be constructed – these days, often in remote, inhospitable, and politically unstable areas – with time frames that are long and increasing. For example, in early 2006, after decades of negotiations, an agreement was announced to construct a natural gas pipeline from Alaska's North Slope to the rest of North America that will likely cost significantly more than the estimated $20bn (in 2001), and it is not expected to come on-stream until 2014, at the earliest (Gold, 2006). On the other hand, according to a recently released report by the US National Petroleum Council, "the average time between a new production technique in the oil industry being devised and coming into general use is about 16 years" (Crooks, 2007).

In addition, those working in the resource sectors over the last three decades are painfully aware of the proven adverse environmental impacts that mine development, production, and processing activities, along with the transport of mineral resources have had and continue to have on air, land, and water quality – nationally, regionally and globally.

Needless to say, if the past is any guide to the future, armed with the projections of global fuel and non-fuel minerals requirements over the next 20-30 years – and the accompanying adverse environmental by-products – scientists and engineers will be able to provide more informed recommendations for regulatory changes in national and global environmental and energy regimes, transport systems, and building codes that can take 20-30 years to propose, debate, legislate, implement, enforce, and assess.

Finally, for some developing countries who are large exporters of natural resources and who also heavily rely on hard currency export revenues from natural resources to pay for consumer and capital goods imports, it would be critical to have global long-term projections of minerals demand to ensure that the necessary extraction, processing, and transport infrastructure will be in place to meet the required mine output levels. For example, there is concern in Chile, which, in 2005, produced 36% of world mine output of copper, that prospects for further expansion are limited in part by a shortage of water and adequate energy supplies, particularly in the Atacama desert in northern Chile, where more than half of Chile's copper output is mined (Morrison, 2006). With sufficient lead-time, feasible solutions to provide the area with the required amounts of energy and water can be proposed, discussed, decided, and implemented.

A BRIEF OVERVIEW OF THE WORLD INPUT-OUTPUT MODEL

This section provides a description of the model – the country and region aggregation schemes, the sector detail, the linkages between the regions, and a very brief overview of the results, that is, a summary of the over- or under-projection relative to the observed data in 2000 for a selected group of fuel- and non-fuel- minerals that was reported in the two follow-up studies (Sohn, 2005 and Sohn, 2007).

The United Nations World Input - Output Model

Simultaneously with the recognition of the increasingly adverse environmental effects caused by worldwide industrialization -- the result, in part, of the increased use of fuel, non-fuel, and water-based resources -- and a major oil crisis in the early 1970s, the United Nations voiced its concerns regarding the growing gap in income, i.e., the standard of living, between the poor, less-developed countries of the world and the richer, highly industrialized ones. As a result, in 1973 the United Nations commissioned the construction of a general-purpose model of the world economy that would be able "to investigate the interrelationships between future economic growth and prospective economic issues, including questions on the availability of natural resources, the degree of pollution associated with the production of goods and services, and the economic impact of abatement policies. One question specifically asked by the study was whether the existing and other development targets were consistent with the availability and geographic distribution of resources" [Leontief et al., 1977].

In hindsight, writing in 2008 -- more than 30 years later -- this modeling effort should still be recognized as an intellectual "tour de force". As far as the minerals sectors were concerned, the model -- which was constructed by a team of economists and computer programmers under the leadership of Professor Wassily Leontief, who was awarded the 1973 Nobel Memorial Prize in Economic Science -- tracked three fuel minerals (oil, natural gas, and coal) and six metallic minerals (aluminum, copper, iron, lead, nickel, and zinc), in addition to some 30 other agricultural, manufacturing, and service sectors, as well as eight types of major pollutants, and five pollution abatement activities.

Economic activity was regionalized -- the countries of the world were (originally) aggregated into 15 regional blocks -- but was unified by export and import flows of goods and services, capital flows, aid transfers, and "cross border" payments of interest on borrowed capital. (Please see Figures 1 and 2 in (Sohn, 2005) for the detailed country aggregation scheme used in this study.)

Once assembled, the model was designed to provide quantitative projections of regional and global resource requirements, pollution levels, cumulative resource use, required inter-regional financial flows, etc., under varying assumptions regarding future income growth in the developed and developing countries with a view towards narrowing the income gap between the two groups of countries from 12:1 (in 1970) to 7:1 (by the year 2000) in accordance with the goal of UN General Assembly resolution 3201 (S-VI) of May 1, 1974 on the Establishment of a New International Economic Order.

In 1977, with financial support from the US National Science Foundation (along with supplementary funding from the then US Bureau of Mines), a team of investigators, again led by Professor Leontief, began a detailed study of the future demand for, and supply of, 26 non-fuel minerals for the US and world economy, embedding 20 "new" minerals into the recently completed World Input-Output Model. One of the principal issues examined in this study was an investigation into the adequacy of these critical resources to meet national and global requirements to the year 2000 and beyond.

Regional production and consumption data for all 26 non-fuel minerals were obtained from various Bureau of Mines reports (Leontief et al, 1983) to reflect regional and global demand-supply balance for 1972, which became the "base year" for developing the regional mineral coefficient matrices for the newlyexpanded World Model.

Once the (1972) base-year data were in place for the 16 regions[1], the 1980 projections of regional minerals consumption and production -- the first year of the long-term projections -- were adjusted to reflect the most recent complete set of physical supply-demand balances that were available (for 1979) when the computations were made in July 1981. (Please see page 214 of (Leontief et al, 1983) for the sources of this data.).

Input-output analysis is a data intensive modeling technique but it is very flexible in terms of the array of questions that the model is designed to address and answer, as we shall see below. For example, regions could be disaggregated into their constituent countries such as was done to the original North America region that was split into separate "regions", Canada and the United States, for the 1983 non-fuel minerals study. In this way, individual countries, with their unique national "endowments" -- such as mineral resources -- and their unique national "constraints" -- such as more restrictive environmental codes -- can be tracked individually.

In addition, projection intervals could be halved to five years on the one hand, and on the other, the terminal year for the projection could be extended further into the future, to 2030, as it was for these studies. And, of course, the sectoral detail represented in the model – again assuming the necessary data is forthcoming – could be expanded as was done for the 1983 non-fuel minerals study (Leontief et al, 1983).

The technique of input-output analysis is also particularly well-suited to incorporate technological change in the economy, and, perhaps more importantly, to assess the impact of

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[1] As a part of the normal upgrading of the World Model, the original "North America" region was divided into two distinct regions – the US and Canada. (For additional information on the methodology used to carry out this disaggregation, please see pages 211-2 of (Leontief et al, 1983)).

technological change on the model's dependent variables, i.e., in this study, the level of fuel and non-fuel minerals consumption. (More about this in Section 3, below).

For any general equilibrium model -- and, in particular, for one that is focused on fuel and non-fuel minerals -- questions regarding the future sources of supply of resources have not only economic but also geo-political implications. The input-output modeling technique is in a favorable position to address supply-side issues such as disruptions that could result from industrial disputes, wars, or politically influenced output constraints. Given the current geo-political stresses, the ability to model national or regional supply constraints – particularly with respect to oil, natural gas, and other critical resources including food – is crucial for the long-term global modeling of critical public-policy issues.

A Brief Report on the Accuracy of the Projections

"An error is worse than a crime."

(Charles Maurice de Talleyrand-Périgord, 18th century French statesman and diplomat)

Table 1, below, presents a very brief summary of the results from the two "revisited" studies cited above. I report the cumulative and annualized percentage over (+) and under (-) projection for the 1980-2000 interval relative to the observed global consumption level for seven non-fuel minerals and for the three fuel minerals tracked in the follow-up studies. The special treatment of mercury, the eighth non-fuel mineral in the "follow-up" study, is explained in (Sohn, 2005). The more detailed information – at the regional or "super"-regional level – appears in (Sohn, 2005 and Sohn, 2007).

The global values reported in Table 1, below, can be considered average "errors", with the "super"-regional and regional "errors" -- which are not reported here -- not surprisingly, having greater variability around these "averages". (These "errors" can be computed from the data in the "follow-up" studies). If the objective of the projections is to ensure sufficient global mining, processing, and infrastructure capacity for the world economy then these "average" errors are the relevant values to be assessed, at least at the outset. On the other hand, if the objective is to focus on national (or regional) consumption (or production), or what policy choices are feasible at the national or regional level to achieve a desired objective, e.g., fuel-feedstock substitution or to address more parochial environmental issues, then the relevant values to be assessed are those at the 16-region level of detail.

In the next two sections I describe the main "drivers" used in long-term projections, how their values can be improved, and finally, how they, in conjunction with the astonishing advances over the last quarter century in computing and information technology, can be combined to improve modeling efforts in the future.

THE PRINCIPAL DETERMINANTS OF DEMAND IN LONG-TERM PROJECTIONS

Population and Income Growth Assumptions

The principal determinants that "drive" demand in general, and the demand for resources in particular, are the growth in income and population – and more precisely, the level and change in per capita income. This is more conventionally referred to as the "standard of living". Long-term global population projections are routinely issued by the United Nations Population Division.

TABLE 1
OVER OR UNDER (-) PROJECTION OF GLOBAL CONSUMPTION OF SELECTED MINERALS COMPARED WITH THE OBSERVED 2000 VALUES (IN PERCENT)

(1)	(2) Cumulative Over or Under (-) Projection: 1980-2000	(3) Annualized Over or Under (-) Projection: 1980-2000
Non Fuel Minerals		
Aluminum	47	1.9
Copper	65	2.5
Iron	132	4.3
Nickel	43	1.8
Phosphate Rock	161	4.9
Potash	229	6.1
Tin	161	4.9
Fuel Minerals		
Coal	92.8	3.3
Natural Gas	-23.8	-1.4
Oil	26.8	1.2
Total Fossil Fuels	35	1.5

Source: Sohn, 2005; Sohn, 2007.

The global population projections for the year 2000 that were made in the mid-1970s for the two studies being discussed in this paper were only 2.3% higher than the reported world population level of 5.97bn people in the year 2000.

Projecting future annual income growth, particularly at the national level, over 20-30 years is a much more ambitious and uncertain undertaking. At the global level for the year 2000, projected GDP was 26% above the actual GDP level, an over-projection of approximately 1.2% per year over the twenty-year interval. (Please see Table 1 in (Sohn, 2007)). While a **projected** global long-term growth rate in income between 2-3.5% per year is an accepted "consensus" interval, at the regional or national level, the 20-30 year **actual** growth rates in income have varied significantly from the above global interval. (Please see Table 5 in (Sohn, 2005)). For example, in hindsight, it is easy to account for the impressive actual growth rates in minerals consumption in the Asia, Centrally Planned (ASC) region (that is dominated by China) and the Asia, Low-Income (ASL) region (that includes the other Asian powerhouses, including India). In the 1970-2000 and 1980-2000 intervals, actual annual income growth in the former region was 8.9% and 9.7%, respectively, and 5.4% and 5.2%, respectively, in the latter region. The actual annual growth rate in income for ASC was more than three times its projected rate, and more than twice the projected rate for ASL. Needless to say, because of the impressive economic performance of these two regions over both the 20- and 30-year intervals – as well as in relation to their projected income growth rates --- absent tin (in ASC), coal, and the fertilizer minerals (please see Tables 6 and 7 in (Sohn, 2005) and Table 8 in (Sohn, 2007)), the observed levels of the other seven fuel and non-fuel minerals exceeded their projected levels. On the other hand, again in hindsight, the disappointing performance of the Russian (and for the purposes of this paper, the Soviet) economy over the 1980-2000 interval can easily explain the collapse in observed demand in general, and of minerals consumption in particular, in that region relative to the projected values. (Please see Table 7 in (Sohn, 2005)).

Sustained income growth in a national economy over the large swath of time of two or three decades is, of course, dependent on an array of ingredients: they include macro-economic stability, a competitive micro-economic substructure (including, but not limited to, openness to trade and foreign investment), a modern institutional and business environment (including, but not limited to, a tolerable tax burden, clear and enforceable property rights, the rule of law, and low levels of corruption), and, of course, an absence of civil unrest or war.

Consequently if a national or regional economy, early in the projection period, experiences a jump in income growth that is sustained over the projection period, as was the case in Asia (the ASC and ASL regions) or, on the other hand, a decline in income as was the case in Russia (RUH) from 1980-2000, these economies will be traveling on very different income-growth trajectories relative to their projected paths over the next two decades. Therefore, the living standards – and, of course, the observed levels of minerals consumption – in these countries (or regions) will be dramatically different -- as they were in the two follow-up studies -- from their projected levels.

With a view to the future, despite the impressive 20-year income growth performance of China (and more recently in India), because of the critical role now played by these Asian giants in the world economy, it would be naïve –if not irresponsible – not to model scenarios in which one (or both) of these countries performed at much lower levels of economic activity, the result of domestic political stresses or of international issues. The same should also be done with other key regions of the world economy such as the major developed countries, even though their past performance has been remarkably stable over the last 30 years (Sohn, 2005; Sohn, 2007). Or, with regard to a more narrowly focused issue, what are the likely infrastructure requirements needed -- roads, service stations, etc., -- not to mention the automobile components, if automobile ownership takes off in China as per capita income continues to increase at the impressive rates recorded over the last 20 years.

Technology-Related Variables

Another important “driver” of economic change is technological advance, especially over a period of time that spans decades rather than years. Since the input-output modeling technique is essentially based on “cooking recipes” for goods and services, the scope for changing the “ingredients” is both wide and deep, and ultimately depends on the availability of relevant engineering and economic, i.e., cost and price, data.

As an example, technological change in minerals use falls into the following categories: first, the substitution of one mineral (or some other material) for another such as aluminum (or plastic) for tin in the cans and containers sector, or the substitution of coal (or uranium) for oil or natural gas in electricity generation. Second, technological change can also be manifested through resource-saving measures, i.e., increased efficiency in the use of a mineral resource. This includes “making aluminum beverage cans with far thinner sheets [of aluminum] and, consequently, less metal” (Tilton, 2003; p. 73), or more fuel efficient vehicles that can be driven more miles per gallon of gas.

Although the input-output technique has the facility to incorporate both of these manifestations of technological change, because of time and budget constraints neither of the original studies (Leontief and Sohn, 1982; Leontief et al, 1983) fully exploited the capacity of the modeling technique to incorporate the expected – let alone the hypothetical – changes in technology that have impacted the use of fuel and non-fuel minerals consumption to the year 2000. For 10 of the 11 minerals re-visited in the two follow-up studies, the observed 2000 global levels of consumption were considerably below their projected levels – natural gas being the only exception. No doubt part of the over-projection in each case was the result of the introduction of resource-saving technologies that regrettably were not fully captured in the model’s “cooking recipes” of the minerals-using sectors.

With a view to the future, the development of path-breaking technologies and their eventual commercialization in the marketplace are likely to take decades. For example, despite years in development, the much-touted hydrogen-based fuel-cell technology to replace the century old fossil-fuel-based internal combustion engine in automobiles can still be decades away from full commercialization. Interim technologies such as ethanol-fueled engines or electric-powered automobiles -- or hybrids -- are being introduced until full-scale commercialization of the hydrogen-based technology (including the required service infrastructure) becomes cost-effective. For example, BMW introduced its Hydrogen 7 vehicle in late 2007 which incorporates an internal combustion engine capable of running on either gasoline (for 300 miles) or on liquid hydrogen (for 125 miles) (Satyapal et al, 2007). Once the new fuel-cell technology is successful it is likely to be adopted globally within years, but decades may elapse before gasoline-fueled automobiles are completely phased out.

The input-output methodology would be in a position to model and provide projections of future oil consumption – the transport sector currently accounts for 70% of total US oil consumption – based on these three scenarios over the next 30-50 years: the “business-as-usual” internal-combustion engine, an interim hybrid/electric powered engine, and the “technology for the 21st century”, the hydrogen-based fuel-cell engine.

Regulatory Changes

Another important motor of change in the national and world economy is regulatory change. Regulatory regimes are legislated locally (zoning laws and building codes), nationally (health, safety, and environmental codes), and, more recently, globally, such as the successful 1987 Montreal Protocol on Ozone Depletion, that banned the use of CFCs because of the proven damage they cause to the earth’s ozone layer. The Kyoto Protocol on Climate Change is another global initiative that was undertaken to control worldwide CO_2 emissions in light of the mounting scientific evidence of global warming that is being attributed to the increasing use of fossil fuels. Global climate change and, more recently, energy-supply security, are the current principal concerns in the major energy-consuming industrialized countries, prodding them to adopt alternative energy systems over the next 50 years (Jaccard, 2005). At the national level, a recently passed energy bill by the US Senate mandates a 40% increase in miles per gallon for 2020 model cars relative to their level in 2007. (The House version passed in August 2007 omits this provision, and the differences in the two bills were reconciled in a House-Senate Committee before the bill was signed into law by the president in late 2007).

Due to the proven toxicity of many minerals, over the last 30 years health, safety, and environmental codes at virtually all levels of administrative authority have addressed these concerns, albeit with long recognition, legislative, and implementation lags that, together, can span one to two decades! For example, in March 2005, the US Environmental Protection Agency announced new rules to control mercury emissions from power plants: the Agency is mandating a 21% reduction in mercury emissions within five years, and a 70% reduction by 2018 (Barringer, 2005).

Needless to say, once implemented, changing regulatory codes that target the production and use of specific minerals have profound effects on the global demand for these minerals. In fact, in the follow-up study on non-fuel minerals (Sohn, 2005), mercury was deliberately selected to highlight this effect. In the late 1970s the US and other developed countries were still years away from phasing out the use of mercury in the traditional end-use markets of paints, batteries, dental amalgam, and thermometers. However, almost thirty years on, because of the regulatory changes adopted to eliminate the use of mercury, there is so little in use today that reliable consumption data for the metal in the year 2000 was not available (and was not, as a result, included in the data in Table 1, above). With a few towards the future, given the current "front-burner" issues of energy security and continuing environmental stress from global emissions of greenhouse gasses, new mandated regulations – much more powerful than those included in the 2007 energy bill that was passed by the US Senate – are likely over the next 20-30 years to confront these two challenges, both from the national and global perspective.

CHALLENGES FOR THE FUTURE

"Projecting economic growth of 16 regions over a period of 60 years is bound to be a tour de force. It will hardly be necessary to wait for the year 2030 or 2000, or even 1990, to demonstrate that most of these figures fall very wide of the mark. The only justification for undertaking such a task is that carrying it out or just examining and criticizing some of its results might lead to a clearer perception of the dimension of the processes involved and, on the more practical side, of the nature of the problems that in one way or another will have to be solved."
(Wassily Leontief, 1982)

Peering into the future -- 25-50 years ahead -- is a science (art?) that is as unappreciated as it is criticized. The outer-bound of the projection interval is still well-beyond the professional life-span of the person(s) carrying out the projections while the inner-bound of the interval -- 25 years into the future -- is long enough for an economy to be subjected to major political, technological, and regulatory changes that can (and do) exert powerful effects on its performance as was discussed in Section 3, above.

In light of the "errors" in the projections presented above, in conjunction with the highly uncertain economic, technological, and regulatory environments faced by those responsible for producing long-term projections, what can (and should) be done differently to improve the usefulness of these models in addressing the critical questions that are part of the public policy debate? My remarks on improving modeling efforts for long-term projections are directed at better exploiting the advances in computing and information technologies, advocating for much more inter-disciplinary interaction in the modeling effort among economists, engineers, scientists, and government regulators, that is, those involved in the knowledge-based sectors of the economy, and making the global modeling effort more amenable to individual country representation as opposed to the more aggregative regional representation in the original World Model.

Incorporating Computing and Information Technology Advances

As I recall, the World Input-Output Model (1975-83) was so large and so expensive to run -- even with the use of Control Data's then state-of-the-art Cyber computer -- that only "one run" of the model per day was permitted, and that "one run" was executed at night! With much greater and faster computing capacity today, modelers would have multiple daily "runs" of the model at a fraction of the cost of 25 years ago. The impressive advances in information technology over the last quarter century have enabled faster and easier access to data and much better data storage capabilities that have facilitated a sharper analysis and more efficient presentation of the results of the projections that improves the ability to receive timely feedback of the results that is so important and useful in scientific inquiry. Together, modelers would construct arrays of different scenarios – best case, worst-case in terms of global and regional economic growth, high versus low (or no) technological change, along with incorporating prospective regulatory changes that, if the past is any guide, could have powerful effects on the regional and global economy in the future. Needless to say, revisions could be made to the model's underlying assumptions -- as the "facts on the ground" change -- throughout the projection interval.

A Call for Enhanced Inter-Disciplinary Interaction

With the benefit of "20-20 hindsight" conferred by examining the 2000 <u>observed</u> data against their <u>projected</u> levels, a few remarks are in order with a view towards improving future long-term modeling efforts in general, and the projections of minerals consumption, in particular. One of the advantages embedded in the technique of input-output analysis is a clearly visible and understandable "black box", which, on inspection, reveals all the "organs, tissues, and bones" – like a CAT scan or MRI – that comprise the structure of a national (or regional) economy.

In my opinion, with greater collaboration among interested business, scientific, and public policy groups, the "black box"-- the complete set of structural relationships that comprise an economy -- can be refined and continuously improved as time proceeds.

If the projection horizon is as long as 25-50 years I would also recommend including individuals who are paid to think about the "unthinkable" long-term geopolitical issues. Again, writing in hindsight, for the purposes of making global long-term projections it would certainly have been useful (in 1980) to have included (at the time) the "unthinkable" scenario of a collapse (and shortly thereafter, dissolution) of the Soviet Union, or the reawakening and integration into the global economy of the two large Asian countries, who together comprise more than a third of the world's population.

In light of the growing scientific evidence supporting the hypothesis of global warming, caused, at least in part, by human activity, any model that is making global economic projections for the next half century would be seriously undermined without an explicit environmental component that incorporates new regulatory directives, tracks energy by source (conventional fossil-fuels, nuclear, and/or renewables such as solar energy), and quantifies emissions and the cost of the their capture or abatement. These could include, for example, the EU's new energy efficiency regulations for electronic goods, especially the eventual phase-out of incandescent bulbs to be replaced with compact fluorescent or sodium vapor lighting. Or, on the other hand, the successor regime to the current imperfect Kyoto Protocol on climate change that expires in 2012.

Alternatively, though this issue goes beyond those discussed in the follow-up studies, in light of today's daunting geopolitical stresses, any model that includes long-term energy requirements should address the important issue of the security of energy-supplies -- securing reliable supplies of energy at reasonable cost in an environmentally sustainable manner -- in the major energy-consuming (and importing) countries. For example, with more and more oil and gas reserves, production, and transport capacity now controlled by national oil companies of countries that are politically unstable and/or openly hostile to the developed energy-consuming and importing countries, serious supply shocks are inevitable over the coming decades as resource competition intensifies as a result, in part, of continuing strong Asian growth. The input-output methodology is particularly well suited to address these types of "supply-side" issues. This is yet another example of the need for, and usefulness of, inter-disciplinary collaboration in modeling these scenarios.

"Nationalizing" the Modeling Effort

In addition to the need for wider inter-disciplinary interaction discussed above, as more and more countries recognize the benefits from their integration into the global economy, economic modelers in these countries will also recognize the benefits of "hitching" their national economic models to a global model. In the original studies using the World Model a quarter century ago only four countries -- Canada, Japan, South Africa and the United States – were represented as individual regions. All the other countries were assembled into 12 broadly defined regional aggregations whose composition today could be justifiably questioned. As a result of the powerful advances in computing and information technology over the last 30 years, the cost and time requirements involved in the "nationalization" of the World Model should be a fraction of what was needed a quarter century ago. Implementing this will, of course, permit the model to better address the important above-mentioned current and future national and global issues of security of energy-supplies and global warming.

CONCLUSIONS

Because of the increasing lead-times needed to supply many of the essential goods and services that are embedded in a modern "standard of living" (which are not limited to only energy and other natural resources), long-term projections are not only useful, but also indispensable. As a result of the long time horizon spanned by these projections, unanticipated political, economic, technological and regulatory changes that occur over the projection interval are likely to have serious consequences for the accuracy of the projections.

In light of the impressive advances registered over the last 30 years in computing and information technology, even large, data-intensive systems like input-output models can be constructed and maintained at a fraction of the cost of a generation ago. Armed with this improved and cost-efficient technology, along with more and more countries participating in global modeling efforts, I am optimistic that with wider and deeper technical and scientific collaboration among the interested parties as described in Section 4, as the facts "on the ground" change over the projection interval, models can be periodically updated as the terminal year approaches, thereby enhancing their usefulness in forging internally consistent solutions to critical problems that enter into the public policy debate.

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