Applying a Biophysical Economics Approach to Developing Countries

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It seems imperative that we as individuals who care about the human condition and about nature must create a new way to undertake developmental economics and perhaps economics in general. The reasons this is so important have been reviewed in previous chapters and include our dissatisfaction with the intellectual foundations of conventional economic models used in development and of the results that have occurred with their use, the general sense of many development economists themselves that conventional economics has failed, the need to do something that will work, the concern that most knowledgeable people have that the future, and especially the future of most developing nations, will be much more constrained by the "end of cheap oil," and the need to protect whatever nature is left. We try to develop such a model in this chapter, summarizing certain approaches and even successes of the past, and use a biophysical basis to try to generate a synthesis to help the reader. We are not foolish enough to believe that we can in one fell swoop cure all the economic problems that generations of traditional economists have not been able to, but we believe that we do provide a useful basis here for beginning that process and for generating useful results now for field workers.

We undertake this analysis with the full understanding that conventional (e.g., neoclassical) economics, for whatever its limitations, is an extremely well-developed and well-integrated approach where, in general, the players are well entrenched and agree upon the rules. And we acknowledge that their influence is increasing in the applied world, even as many academic economists step back from the pure model. For example, "computable general equilibrium" (CGE) models, which are pure applications of NCE, are increasingly used in world trade organization (WTO) negotiation rounds that affect billions of lives. In addition conventional economics has been developed in such a way (e.g., by emphasizing money rather than energy, demography, and other resources as we do) as to appear to be a logical extension of the day-to-day economics with which we are all familiar. These are significant hurdles to overcome for those of us that believe that a more useful and accurate economics can be developed. Nevertheless we perceive the importance of this to be so great as to require our best efforts to do so. A point in our favor is that we know that we are not alone in challenging NCE, and our best allies may be some of the economists themselves, especially those who spend their time in the realities of the developing world.

We have spent considerable time in the past developing a biophysical assessment for the country of Costa Rica, and much of what follows is based on our experience in that assessment [1]. That book has 26 chapters with detailed assessments of essentially all important aspects of the Costa Rican economy. It has in addition (on a CD bundled with the book) a comprehensive and user-friendly visualization and model that we think is extremely important in communicating biophysical information and assessments to both other professionals and also to lay people. The basic idea of the main visualization and model is that there is a central image—that of the country of Costa Rica, shown with the mountains visible in a three-dimensional representation—with ten small graphs around the edge with lots of different information that is plotted over time as you watch the rather amazing deforestation unfold in the central image and the green, forested country turns to agriculture and pastures represented in yellow, while the numbers of humans, cows, hectares of used and degraded lands, and so on grow nearly exponentially on the graphs around the margin.

One characteristic of these analyses—which may be good or bad depending upon your point of view—is that there is (usually) no attempt to reduce the various different information sets to a single scalar (such as is usually the objective in, e.g., money-based economic cost-benefit analyses). Rather the idea is to put all of the dynamic information, including land use, demographic, environmental, economic, and so on, on the screen simultaneously and then let the user or decision-maker (or the people effected) decide whether they prefer the existing path of development (by whatever criteria they choose) or might rather have something else. This approach can be particularly effective when integrated with historical patterns of, e.g., land use. Most people living in Costa Rica today are too young to understand how much their country has changed in one human lifetime, but they can see that clearly –and are often amazed—when they see this as an n-dimensional visualization. So most of the rest of this chapter is a discussion of what kind of information you might want to include in such a visualization or perhaps in some simpler analytic structure such as a spreadsheet. The model allows for the implementation of policy and the observation of how that would effect the many parameters. When shown this model, Oscar Arias, the former President of Costa Rica and Nobel Prize winner, said to Hall "I like it. It forces the decision-maker to see the consequences of his decisions". Would we have such a model for the present United States and a president who would pay attention to it!

A rough guess as to the cost of developing the kind of overall biophysical analysis for a small- to medium-sized developing country is on the order of one to ten million dollars, assuming that you are undertaking this analysis with competent and not greedy investigators and that the biophysical and economic database is well developed, as was the case for Costa Rica. Our very thorough assessment of Costa Rica was done on a small fraction of that, although much of the work was subsidized with sabbatical pay from Hall's university, essentially free graduate student help, other projects that had already funded Leclerc, and the data, interest, skills, and good will of numerous Costa Ricans. Most of the examples we give here are aimed at such a national level, although the biophysical approach that we are advocating is in theory applicable at any regional level that the investigator might choose. The most important scale issue is that much of the data is generally most readily available at the national level.

21.1 Other Somewhat Related Biophysical Approaches

Before we give our own approach, we think it is useful to review a number of other biophysical approaches that have been developed either to evaluate/assess specific environmental impacts of economic activity or for some other explicit reason. While these approaches do not give the full and comprehensive environmental and economic analysis we advocate, we think it is important to review them as they can be very useful supplements to the analysis that we give below.

We would also like to emphasize that our attempts to build a biophysical assessment are only marginally related to most of what is being done under the aegis of "environmental economics" or even the bulk of the activity in "ecological economics." Although the goal of environmental economics (and a substantial part of ecological economics) is to integrate the environment into economic analyses, in fact it has been mostly about putting a dollar price tag on all kinds of environmental objects and services, and while we applaud such analyses, that is not at all our objective here. One basic reason for this is that we believe that the dollar or other monetary unit is basically defined in market situations for nonessentials, the demand for which hardly represents real human wants and needs because it is often tremendously influenced by advertising. In addition dollar values often give extremely poor information about basic resources: for example, as wild salmon increasingly are disappearing and are hence of less and less value to our society, their price goes up indicating they are becoming more valuable than when they were cheap and abundant!

Hence we believe that giving a dollar value to many things is often a rather poor estimate of the value of our most prized things, including our relations to those people close to us, justice before the law, the maintenance of natural environments, and the milieu of the Earth that allows us to exist here in the first place. In fact all of these are under assault by dollar-based aspects of our economy, and hence in our opinion, dollar-based criteria are not appropriate for making assessments of the value of nature or our most essential resources. That said we of course realize that we live in a monetary-based world where many things must be valued in monetary units for routine day-to-day transactions. So we try to walk an appropriate tightrope between using and not using monetary estimates.

The first assessment procedure we review is to examine the environmental requirements for a given region (for our purposes a social and economic unit such as a country or city) in terms of the quantity of land required to support the activities on that area considered. The most comprehensive and thorough such analysis is called the ecological footprint which is run by Mathis Wackernagel [2]. For example, they found that the land area required to support the needs of the city of Vancouver, Canada, was about 18 times the land area of the city itself. This included land areas needed for growing crops and producing cows, fish, and other animals consumed, growing timber, mining minerals, and so on (about half the area required) as well as assimilating the sewage, toxins, CO_2, and other wastes produced (the other half). Such assessments always show that the areas actually in use supporting people are much greater than the areas the humans actually occupy and give lie to those who say that the Earth can support much larger human populations (or even the present level) indefinitely. They conclude that about three Earths are needed for today's population and level of affluence if we are to live on income rather than by running down capital. Over time the authors have developed and refined their methodology impressively and made its use on their website very straightforward and easy. Because they trace back virtually all the major material substances used by different groups of people, their complete list of material used constitutes a ready-made list of the biophysical materials required to support an economy. What they have not done yet is to relate the materials required to the level of monetary activity or ask these questions of developing countries. Once this is done, we will have one rather good biophysical assessment at our fingertips.

The second approach is to undertake energy analysis, which in its many variants means essentially how much energy does it take to undertake various economic activities. These methods were developed most importantly at the University of Illinois in the 1970s by Bruce Hannon, Clark Bullard, and Robert Herendeen and were applied to most aspects of our economy including agriculture, manufacturing, provision of services, and so on [3–5]. A feature of these studies was that they calculated not only the direct energy used (such as the energy used in a tractor factory to make the tractor) but the indirect energies as well (i.e., the energy to mine and refine the iron, plastics, and so on used by the tractor factory). As a rough estimate, about half the energy used to make some product sold in "final demand" occurs in obtaining and refining the raw materials. Summaries of the results of such studies are given in the above publications and Hall et al. [6] and Cleveland [7]. An important aspect of this research is that the numbers are old, as there has been little Federal funding of such energy research for decades as energy analysis has fallen into political disfavor or, more accurately, indifference, because in the minds of many (but not us), the market has resolved the energy issues of the 1970s. However a recent study by Carnegie Mellon has updated these analyses to 2002 (by methods that seem pretty defensible according to Robert Herendeen), and these estimates are readily available on their website [8]. Sergio Ulgaldi and his students at the University of Naples are putting together a web-based system for calculating the material costs for many different commodities (e.g., a new building) including the associated environmental costs.

Howard Odum, Mark Brown, and others have argued that, while the above energy analysis is useful, it is incomplete because it does not take into account either the environmental energies required to manufacture something or correct for the fact that different types of energies have different qualities. For example, a kilojoule of electricity has value to society beyond its ability to simply heat water and hence more value than a kilojoule of coal, because of its special properties and because it takes about three heat units of coal in a power plant to produce one unit of electricity, the rest more or less of necessity being released into the air and water. Likewise a kilojoule of sugar fixed by a plant has more value than a kilojoule of the sunlight that made it and so on. Odum has generated the idea of embodied energy or more explicitly emergy (with an m, as in energy memory, a concept analogous to the embodied labor, or total energy required to make, in a manufactured item) as a term to reflect the various qualities of energy. Odum and his student Mark Brown have developed an extensive accounting scheme to measure this and to compute the quantities of emergy required to make, or cause to happen, many things [9–12]. Transformity is a word used to evaluate the different qualities of different types of energy. An advantage of this approach is that it is obvious that if we want to account, e.g., the oil used to manufacture something, we are missing all together the large quantities of environmental energies that are just as much needed to make it. These energies include, for example, the energy used to distill freshwater from the sea and lift it to mountain tops which allows it to form rivers and hence become available to plants and to humans. Likewise the sun runs photosynthesis and everything that derives from that even though we do not pay Mother Nature for either the water or many of the products of photosynthesis. In addition it includes in the analysis an emergy assessment of the environmental services foregone because of the activity in question. While the idea is tremendously appealing to us, and the comprehensiveness essential in our view, the difficulty in estimating transformities makes its use less desirable to some.

It may be that all of these techniques are measuring something quite similar and that their utility may converge. Their use has not been compared often. Hall, Brown, and Wackernagel compared the carrying capacity of Costa Rica for humans using a comprehensive economic approach that went well beyond market costs, as well as two biophysical assessments: ecological footprints and emergy analysis [13]. The results of the three approaches were very similar, giving hope that we are approaching a true cost using both biophysical and comprehensive economic analysis. However, although each of these procedures is helpful in assessing a biophysical economic analysis, we still feel that it is useful to generate a more explicit summary as to how we can undertake biophysical economics. We do this below; however we look forward to the day when scientists and policy makers agree on a set of assessment procedures to be integrated in one useful package. We look forward to the time in the not too distant future when as part of the biophysical analysis of any item or activity all that would be necessary would be to go to one website, maintained by skilled professionals, and type in the quantity (in tons or dollars of a particular year) to get all of the material, energy, emergy, footprint, environmental degradation, and so on associated with that economic activity. A step in that direction is the triple bottom-line approach (economic, energy, and environmental) of Barney Foran, with free software available to help with the assessment [15]. Later this can be done also for different countries or international corporate entities to give more explicit values. Perhaps someday there will be a label on your breakfast cereal that gives, in addition to calories and sodium per serving, an assessment of the fuel and solar energy required to make it as well as the soil and biodiversity loss, maybe all summarized in terms of energy.

21.2 Explicit Procedures for Creating a Biophysical Economic Analysis for a Country or Region

While we wait for this future web-based synthesis, there is a great deal of quantitative analysis we can do and in fact that can help provide the basis for this web synthesis. We base what follows on our earlier work related to preparing our previous book *Quantifying Sustainable Development: The Future of Tropical Economies* [1]. This assessment included extensive discussion of our (and others) biophysical approaches with contributors and our extensive previous experience with assessing land use change [15, 16]. We also base our assessments on simply living for much of our lives in the developing tropics (especially LeClerc, who has done everything to escape his native Canadian winters) and reading a large number of newspapers and scientific papers there. Hall [1] represents the most serious attempt to date to develop a complete biophysical economic model of a national economy which we summarize and extend in this chapter.

We will be the first to recognize that this is a very imperfect activity, that we are just learning how to undertake such analyses, and that there are many changes that will be developed over time. Nevertheless we have found that this approach in part or in full has served us and our colleagues and students well for analyzing many basic characteristics of a country or a region.

We have come to the conclusion that there is a way to undertake routine biophysical economic analysis, including a rapid assessment of development, and to use this process to help construct better development schemes. We propose a methodology that unfolds in five steps that can be put simply as:

Step 1 State your objectives (with the right people including your critics).

Step 2 Assemble a time series database of critical biophysical parameters.

Step 3 Make an assessment of critical economic parameters with as much data as possible from the past.

Step 4 Construct a comprehensive simulation of the future.

Step 5 Make the right decisions.

We assume that after these steps are taken into account for devising a development scheme, money will flow in the right directions; schools will be built, equipped, and populated; and institutions will improve. Nevertheless we are also quite aware of the potential for, e.g., corruption of leaders to undermine our efforts. Does the use of explicit and open science make corruption less possible? We think so but do not really know! Part of what must be done is the professionalization of all government institutions and personnel, including accountants.

21.3 Step 1: State your Objectives (with the Right People)

It is not possible to undertake a journey, no matter how sophisticated your vehicle, if you do not know where you are going (unless of course your objective is simply the activity itself). So the first thing to do in undertaking a biophysical assessment is to ponder, discuss, and then state explicitly your objectives. Often people confound problems and objectives. An objective should not be a series of problem-solving activities; it should be seen as a long-term desired future condition. For the Costa Rica study [1], the main objective was to determine to what degree, and in what ways, the country was or could become sustainable. This led logically to the next set of objectives which was then to determine what we meant by sustainability, which in turn led to some interesting literature that showed that very different people had very different perspectives on what sustainability meant, most of which were antithetical to each other!

A second part of this analysis is to examine what objectives people had in the past for related issues and how well these were achieved. In other words, a review of pertinent literature both for the region being analyzed and also of past public and private development projects, their objectives, procedures, successes, and failures. Many of these analyses use (or should use) time series data of, e.g., economic, agricultural, or other data. It simply is not possible to understand whether whatever plan you are undertaking is successful or not unless you have a yardstick of the past trends in time to compare it to. An important issue is to state objectives as hypotheses which then can be tested, something that is rarely done. While it is often difficult to test hypotheses, one can often restate policy objectives as hypotheses and then see if ensuing data are consistent with that hypothesis or not [17].

Very often the objectives will be stated in social, economic, or environmental terms. Given that we agree with that perspective, the reader might be curious as to why we then focus so much on the biophysical aspects of analysis. The answer is simple: we believe that social, economic, and environmental issues must be addressed and, where possible, resolved within the context of the biophysical systems within which they must take place. It is very easy to list the various things that you would like to have: higher incomes with greater equitability, less pollution, greater welfare, and so on. Given that for the developing world these and other objectives are very often not met means that there are serious constraints. Some of course are social, and we include here especially corruption and the very unequal distribution of whatever wealth is available. But much of what gets in the way of achieving one's social or economic objectives is biophysical, including resource availability, climatic constraints, and biophysical mismanagement including, for example, overfishing, soil erosion, fuel limitations, ability to generate foreign exchange, and so on. It is important to understand what these are or might be.

And it is especially the biophysical aspects of development that have been neglected during decades of neoclassical economic policies. Therefore the biophysical context must be restored in mainstream thinking, possibly as the framework within which the social and economic possibilities are considered, hence our biophysical emphasis, although we in no way wish to diminish the importance of the social, political, and economic elements. In fact we believe that the reader will find that most of our papers try to integrate the biophysical and the social sciences toward attempting to meet their objectives.

If we are interested not only in the progress of science but also in its impact in the development of the country studied, then we have to find the right people to develop the models with. These people will help at many levels: to clarify the objective, to obtain the data (not easy in many developing countries), to provide key insights to interpreting the data and for prospective analysis, and to make the connection with policy so that we can extend its use beyond the scientific paper. If we are all involved from the start in developing an analytic model (i.e., "companion modeling") [19], there is a good chance that we learn from each other and end up with a model (or a family of models) that is not only more relevant but one that will continue to be used for policy making. Allan and Holland, and Beaulieu in [17] give several hints about how to identify who you should work with and how to connect to a development process. A good starting point is to do a stakeholders' analysis and work, with the right people, on a shared vision for the country or region. This is where genuine objectives will appear more clearly to all and when the collective learning process will begin.

21.4 Step 2: Assemble a Database of Critical Biophysical Parameters

The first step in undertaking biophysical analyses (once past time trends of pertinent data have been prepared) is normally to determine the physical characteristics of the country or region being analyzed. Such analyses are far easier than in the past due to the increased availability of good digital summaries compared to 20 years ago. An example of how such a database has been developed is given in Barreteau et al. [19]. The best way to do this is to generate an assessment of the physical resources of the region in question.

An essential requirement is a summary of energy resources including any known oil, gas, and coal deposits; assessments of what might be found in the future; developed and potential hydroelectric, solar, and wind potential (for which you need meteorological information); biomass possibilities; and so on. In all of these assessments, it is important to realize that in general the better resources were developed first, such that increased exploitation may be more energy and monetarily expensive. For all of these generate a time series of their use.

But different types of energy have different properties or qualities, and often it is useful to take that into account. Generally the data available will be in the form of heat units (i.e., therms, BTUs, kilowatt-hours, kcal, or the most commonly accepted units used today which is joules). By heat units we mean that the energy is measured by its ability to heat water, for example, 1 kilocalorie (kcal) is the energy required to heat 1 kilogram (about 2.2 pounds) of water 1 degree centigrade. These units are all intraconvertible and there is no real difference among them. When fossil fuels are compared to electricity generated from hydro or nuclear power, it is generally best to multiply them by a factor of about 2.6 to account for the difference in their ability to do work and also their opportunity (or conversion) cost if they were made from fossil fuels. Additionally we need to undertake an assessment of the various environmental energies that must be supplied for the economy to work properly. As stated above this can be done most comprehensively using an energy analysis.

Similar assessments are required for natural resources that are not energy sources, such as:

1. Nonfuel mineral resources, such as metal ores. The important components of this are the size of the reserve (in tons), the quality (i.e., percent metal in ore, both at present and as exploitation proceeds), the depth and ease of extraction, the energy cost of extraction of different amounts, and so on. Since in general the best grades were used first in the past, the remaining resources may not be as cheaply or profitably exploited as was once the case. Since often the exploitation of minerals occasions significant pollution, any such impacts, and a social and monetary estimate of that damage, must be made before the project begins. These issues must be considered in addition to expected market prices and other routine economic factors.
2. Water resources, both quantitatively and qualitatively, first in overview and then spatially. Some of the information that needs to be generated or summarized includes rainfall and flow of major rivers (both as a mean and for drought and wet years), ground water resources and their vulnerability to depletion/salinization, evapotranspiration and soil moisture over space and time, water bodies that are significantly polluted, and so on.
3. Land resources for examining agricultural (and other) potential, i.e.:
   - A soil map, ideally with the soil units related to crop productivity, including where possible potential and actual erosion
   - A digital elevation map
   - A land use map

21.4.1 Taking Demography into Account

We believe that fundamental to what one is trying to achieve with almost any biophysical model is a proper representation of human demography. Fortunately, excellent datasets exist for less developed countries (LDSs), from nationwide census data every 5 or 10 years to yearly estimates based on samples in between. (Note that because NCE is based on the behavior of individual firms, it is insensitive to demography!)

For prospective analysis it is necessary to generate a demographic model based on actual demographic data. One simple model is:

$$P_t = P_0 e^{rt}$$

where P is the population level (normally in millions), P_t is the population at time t years into the future, P_0 is the population at some initial time t, the natural log of e is approximately 2.718 and r is the "intrinsic rate of growth," the rate at which the population is growing or, better, is expected to grow. The value r (in units of proportion of the existing population per year) is the birth rate (b) minus the death rate (d). Hence the term ert is a number that will usually be greater than 1.0 and will be the factor by which the population is larger (relative to the initial population) over time. The doubling time of a population can be calculated by dividing the number 70 by the growth rate expressed as a percentage, so, for example, a population with a 2 percent per year growth rate will double in 35 years. This simple model is often reasonably accurate, at least within the restrictions of knowing the value of r, for a few decades.

But there have been many who believe that to continue to use an exponentially growing model is seriously flawed, as populations cannot grow exponentially indefinitely as they would run out of food, resources, and/or space (i.e., carrying capacity). Some models, attempting to represent that fact, will assume or simulate some sort of empirical plateau, (in other words, r diminishes) or saturation of growth. A logistic or S-shaped curve is used often to simulate that saturation effect. Although the logistic equation is simple and has some perhaps good logic behind it, in fact few populations in nature follow that pattern, and attempts to use that model to predict human populations in the past failed miserably. The debate between "implosionists" and "explosionists" is still alive (because the data support either view equally well), and while the S-curve is still the most widely used distribution for making human population projections in less developed countries (LDCs) (see ► www.prb.org), the beginning of the plateau could be put at any time after 2050.

Both the exponential and the logistic model have a number of liabilities, including that they are not sensitive to changing values of r over time and are insensitive to the more detailed demographics such as the number of pre-reproductive vs. post-reproductive females, and of course they are for only one geographical unit. More complex and accurate, or at least sensitive, models can be made using what is known as a Leslie matrix, which is usually solved in a spreadsheet or a computer program. A simple example in FORTRAN is given in ◘ Table 21.1. Data for all of the world's countries can be obtained from FAO or the CIA database. Sometimes the growth and death rates are given for 5-year intervals when annual values are needed. To use this data, it is necessary to enter the data into a spreadsheet such as Excel and fit, e.g., a second- or third-order polynomial to the data to get a relation from which you can generate values for each year as well as predictions into the future.

Additional demographic information can be developed including poverty assessments, health, and labor productivity.

Additional geographical information needs to be developed on the location and extent of built infrastructure including cities, villages, transportation, industries, ports, airports, protected areas, land tenure (private and public), and so on. These can be built into additional geographical information systems (GIS) data layers as is well understood from conventional GIS analyses. This information is useful in understanding the accessibility of resources to populations and as drivers for predicting land use change. Often our overall objective is to simulate how future land use, economic, and food security scenarios might be as influenced by demography, erosion, policy, climate change, and so on.

21.5 Step 3: Make an Assessment of Critical Economic Parameters over Time

The first step is to undertake an assessment of the current economy and its recent history. There are a number of locations to find *empirical*

Table 21.1 A simple Leslie matrix in FORTRAN

```
PROGRAM LESMATRIX
!**************************************************************************
! Dictionary:
!**************************************************************************
! ACLS              = Age class of the human population.  1 equals all people before
!                     their first birthday, 2 = all people between their first and
!                     second birthday and so on.
! PopNum(YR,ACLS )  = Population number for each age class for each year
!                     This state variable is updated each year.
!  DRate(ACLS)      = Age-specific death rate
!  Births (ACLS)    = Number of births per year per female by age class (this may be
!                     known only on average)
!**************************************************************************

!**************************************************************************
! Define variable type:
!**************************************************************************
INTEGER PopNum(100,100) , YR, ACLS
REAL DRate (100), BRate(100)
!**************************************************************************

!**************************************************************************
! Open read and write files      :
!**************************************************************************
 OPEN (1,FILENAME = "LeslieMat.DAT", Status = "OLD")
 OPEN (2,FILENAME = "LeslieMat.OUT", Status = "UNKNOWN")
! Read in initial population numbers (in thousands or millions) & age-specific death rates
!**************************************************************************
READ (1,900) (PopNum(1,ACL), ACL= 1,80)
READ (1,900) (DRate     (ACL), ACL = 1,80)
READ (1,901)  BRate     (ACL),ACL = 1,80)
! Write output headers:
!**************************************************************************
WRITE (2,902) "Table 1,  Population levels by age class"
WRITE (2,903) "Year  Age Class >" , (ACLS(I), I = 1,80)

! Solve equations annually for 50 years starting in year 2000
!**************************************************************************
DO YR = 1, 50
          Ryr = 2000 + YR                  ! Real Year
          PopNum(Yr,1) = BirTot             ! Births from end of last year considered age class one

          ! Do for 80 year classes (assume 80 is oldest year people live or at least reproduce

     DO ACLS = 2,80                        ! New members of first age class already added in as births
          Births  = RepPop * BRate (ACLS)  ! Sum up number of potentially reproducing females
                                            ! (here age 15 to 50)
                                            ! Move each year class forward, reduced by their
                                            ! death rate
          PopNum(YR,ACLS) =  PopNum(YR-1,ACLS-1) –(1.0 * DRate(ACLS)
          IF (ACLS.GT.15.AND.ACLS.LT.50) RepPop = RepPop + Pop(YR,ACLS)
          BirTot = BirTot + Births
     END DO
   WRITE (1,904) YR, (PopNum(YR,ACLS), ACLS = 1,80)
END DO
!**************************************************************************
!Format:
!**************************************************************************
900 FORMAT (80I6)
901 FORMAT (F8.2)
902 FORMAT (A20)
903 FORMAT (A15,80I6)
904 FORMAT (15X,80I6)
!**************************************************************************
END PROGRAM LESMATRIX
```

*Source: Charles A.S. Hall, with the assistance of Athena Palmer information for this, but probably the easiest is to get the data off the web, generally by using Google or another search engine. Good sources are the large multilateral organizations (United Nations Food and Agricultural Organization, United Nations Development Programme, World Trade Organization, Non Governmental Organization, World Resources Institute), and the unavoidable World Bank. Several organizations provide country fact sheets, the US Central Intelligence Agency Fact Book (► http://www.cia.gov/cia/publications/factbook/index.html/) and The Economist (► www.economist.com/countries/), and as the digital divide gets narrower, there are more and more data from LDC government sites available. These government sites often contain key documents on policies, feasibility studies, law texts, economic summaries, etc. Travel books are quite useful to have a grasp of country's idiosyncrasies. A problem with many sites is that there is no time series data which makes the FAO (Food and Agricultural Organization of the United Nations) data probably the most generally useful, as they have data back to 1961.

From this information a time series of economic activity can be derived. Some data we suggest might be considered include a time series of basic monetary economic information, including GDP over time.

While any analysis of any raw GDP data almost always shows a rapid increase over time, this is very misleading as much of the increase is due to inflation. So the first thing to do is to correct the data for inflation, normally by expressing all data in terms of monetary units for 1 year, for example, "2000 dollars" or "2004 Pesos." This is done by using "implicit price deflators" (the easiest ones can be found in the "Statistical Abstracts of the United States"). This is especially useful when dealing in US dollars, although it is more accurate to use corrections implicit for the country in question. In the United States and many other countries, there are also more specific correctors for different sectors of the economy, for example, for energy and for food.

A second step is sometimes required, which is to make an additional correction for purchasing price parity (PPP). If a nation's GDP is corrected for inflation relative to the US dollar, as it often is, it is also necessary to correct for the fact that the increase in prices expressed in dollars does not reflect the fact that there is often far less inflation for local products such as food than, e.g., imported computers or fuel paid for in dollars. On the other hand, if you are interested in the issue of how much, it costs for e.g. imported oil (which must be paid for in dollars or euros), then correcting for PPP is not useful. Since for many developing countries the inflation rate applied to dollars is considerably greater than the rate applied to local items, this can be an important issue.

To express the meaning of the GDP changes (corrected as appropriate as given above) in terms of how it effects the average person's ability to purchase goods and services, the total national GDP, corrected as above, needs to be corrected to per capita values. The total national GDP tells you little about how well individuals in that country are doing in terms of their own economic welfare or purchasing power. Dividing the total wealth production by the number of people gives you per capita wealth, which is roughly proportional to at least some important aspects of the average person's material well-being. To do this one simply divides the total GDP (corrected as above) by the number of people in the country for that year to get the per capita GDP. This then results in a decrease in the effect of GDP increases and in many cases where the population increases more rapidly than the GDP people, on average, get poorer.

Even per capita changes do not tell the whole story, for most of the GDP may go to only a relatively few people. One way to examine this issue is to use or compute the "Gini index," named after Italian economist Corrado Gini. This measures the degree of inequality in a society. If there were perfect equality, the Gini coefficient would = 0. If nobody except the richest individual had any money, the Gini coefficient would = 1. Therefore, the larger the Gini coefficient, the greater the degree of inequality. In 1968 the Gini coefficient for the United States was 0.388, by 2015, it had risen to 0.480, indicating a substantial rise in the degree of inequality.

An extremely important aspect of sustainability is whether a nation is able to do whatever economic activity it does without going into international debt, which tends to be a killer aspect of development that leads many otherwise excellent development schemes into failure. Since the desire for foreign products, both those essentials, e.g. for the development of food production but also luxury items, requires payment in foreign exchange, that is, dollars or euros, it is essential for a country to export enough to pay for these items. The alternative is foreign debt, which in many countries is more or less the largest problem in making an economy that works. Costa Rica, for example, needs to use about 15 percent of the foreign exchange it generates through the sales of bananas, coffee, and tourist services simply to pay for interest on its foreign debt. It uses perhaps another 20 percent of the foreign exchange it earns to pay for the generation of the exports, i.e., for the fertilizers, plastics, and fuels required to make bananas. Since there are enormous demands in Costa Rica for imported items (from cars, buses, and trucks to fuel to run them, to computers, to apples) and a rather limited international demand (or more properly a huge oversupply) of bananas and coffee, then it is real tough for countries like Costa Rica not to get into debt. On top of this, governments often borrow from external banks to, e.g., make payrolls or provide health services. While Costa Rica has done much better than many countries (including the United States) in not running up external debt, it is a very difficult issue. Hence it is useful to plot imports, exports, and their difference, as well as debt and its accumulation or decrease over time.

Another issue that contributes to a large difference between imports and exports is that developing countries tend to be desperate for development capital and that capital is rarely available internally. So, for example, Costa Rica needs more electric power as its economy grows, and that can be supplied by developing more hydropower. But the Costa Rican government does not have the investment capital for that. So Japanese power companies are more than happy to build the hydropower plants that are needed because they are happy to collect the revenue from those plants. The problem is solved, sort of, but there is a new revenue flow out of the country. The point is that development projects need to be examined not only from the perspective of their promised gains but also their costs including, of course, their costs and gains to whom.

21.6 Undertaking a Biophysical Assessment of the Current Economy

The next major step is to look at the biophysical resources needed to make the economy do what it does and, presumably, to do more of the same in the future. Since we also have developed time series of economic activity and also time series of energy used, we can quite easily develop the energy intensity, which is the energy used per unit of economic activity, either for the economy as a whole or for some aspect of interest. This is the first step required to understand the biophysical resources needed for the operation of the economy. A similar concept (actually the inverse) is assessing the *efficiency* of an economy. In general efficiency is the output of a process divided by the input. *Efficacy*, a similar sounding but very different term, is the effectiveness of some activity regardless of the efficiency; in other words it is getting the job done. For example, we might say that the US economy is very efficacious, that is, it produces a great deal of goods and services. But its efficiency, that is, the total dollar value of its output compared to the quantity of energy used to generate that wealth, is rather low compared to many other nations. One straightforward measure of efficiency that we might want to calculate then is the output of the economy divided by its energy input, which if we have the information derived above we can do very easily in a spreadsheet or computer program. The efficiency of the economy can be seen by the ratio of the two and the changing efficiency by the changing slope of that line.

A critical issue is that most developing countries are dependent upon imported petroleum, which is unlikely to be indefinitely cheap or even available [19]. Thus contingency energy supplies and their potential cost need to be considered. Increases in energy prices tend to raise havoc with LCDs. For oil-producing countries that have become dependent upon revenues from petroleum, peak oil, which is inevitable, tends to cause political chaos [20].

Depending upon the objectives of the study, other indices can be used, such as imported vs. domestic energy or GNP per unit of water, or agricultural production per unit of energy or fertilizer used, or GNP per unit foreign exchange gained or lost or many other objectives. When we have done these analyses in the past, we have often found that GDP increases more or less in step with energy, water, fertilizer use, and so on, so that efficiency does not change much over time. This has important implications for the economic aspect of efficiency for if efficiency is not increasing that implies that the only way to generate wealth is through the further exploitation of resources, something that has ultimately serious environmental and supply implications. Much more detailed analyses can be undertaken through the use of input-output analyses.

An important aspect of a biophysical (or any) assessment is that there are often not clear ways to achieve several goals at once, and one is left with trade-offs. Several of the chapters in this book are focused on that issue. Finally, development projects that were once very good often crash over time, as is classically illustrated with wild fisheries and aquaculture. These crashes are often, but not always, predicted through fishery science but not ever, to our knowledge, through market assessments alone.

21.7 Predicting the Future Energy Needs of a Society

Presumably any such biophysical analysis will show that the economy of the region is moderately to very energy intensive and that any expansion of the economy is likely to be even more so. Most development is presently based on oil. Thus future expansion of the economy presupposes the physical and economic availability of oil or at least some other equally useful form of energy, if that exists (which we doubt). At present there are about 38 oil-exporting nations. The economies of most of the smaller- and medium-sized exporters are becoming themselves much more energy intensive over time, and most will become net importers themselves within decades as their own domestic use intercepts their production [19, 20]. Thus it is important now to consider how, if economies are to be expanded, that might be done in a way that makes them dependent upon perhaps unreliable or at least very expensive future oil supplies. This is an issue not normally considered within conventional economics as the present market price of oil makes it a seemingly attractive choice. But we feel it important to go beyond that mentality. As of this writing (July 2017), there have been both large price increases and declines recently in the price of oil, although correcting for inflation it is often still higher than in the past decades. One of our colleagues in Great Britain said that he felt he was standing on the shore of the North Sea and although the storm had not hit yet the first large waves were starting to roll in. In other words the price increases that we have observed recently are only a small sign of what lies ahead as the world truly approaches the end of cheap oil. What this will mean for the world can only be guessed at, but for the non-oil-producing nations of the developing world, the impact is likely to be enormous as populations and economies that had expanded based on cheap oil have the rug pulled out from under them. It is unlikely to be a pretty sight.

21.8 Predicting Land Use Change

An important part of many assessments of the future capacity of a nation or a region for providing economic or environmental services is an assessment of how much land is available in different categories (this is loosely related to the concept of ecological footprint). The principle tools for doing this are several computer models that start with one map of land use for a given year and then make assessments of what the land use might be in the future based on rates and patterns of development. Both rates and patterns tend to be derived from existing patterns that can be extracted digitally from one or more existing maps of land use. One of our favorite models for doing this, not surprisingly, is one that we derived ourselves. This model, called GEOMOD, is bundled with the most recent version of IDRISI, a commercial software package with powerful modules for assessing and predicting patterns of land use [1, 16, 21, 22].

One might start with, for example, a map of the forested vs. non-forested region of Costa Rica, as we did in our original analysis. It had been our experience based on looking out airplane windows while flying over many regions of the tropics, especially the hilly or mountainous tropics, that development tended to start along rivers, often at lower elevations, and then work progressively up stream and upslope over time, with the development usually proceeding from one already developed place to an adjacent forested one. This is consistent with the idea that farmers will develop land in a way that represents the least effort or energy investment on their part (hence adjacent properties on flatter land) with the highest potential for agricultural production (usually soils near a river on flatter land). Our first assessments used a DEM (digital elevation model) to represent topography, with originally the land represented as a checkerboard of 1 kilometer by 1 kilometer cells, each of which was assigned a one for forest and a two for deforested land. We would provide GEOMOD with an initial or start-up map, with the areas developed or deforested for a particular region represented by one and the original forested area represented by two (or with more categories, another number, or color when displayed). We then used a search window to search row by row and column by column for cells that had already been developed, meanwhile examining the nine (or sometimes more) cells around each developed cell using a process called "adjacency" as one criteria for which cells are likely to be developed. If there was a non-developed (forested) cell next to a developed cell, then we had an "edge," and that forested cell was a candidate for development. This was done for the entire map, meanwhile keeping track of the elevation and/or slope for each candidate cell. Then enough of the lowest elevation (and/or flattest) cells were developed to meet the proscribed rate of development expected for that time step (usually 1 year). Over time this process will result in the spread of development upstream and upslope, simulating a basic pattern by which humans use land. The final project will be maps of human use of land into the future.

It is worth mentioning that it is imperative to reexamine, on a regular basis, our assumptions on farmer's decision-making rules. This typically involves interviews and surveys in the field. Often we find that what we thought initially was wrong, even if it seemed perfectly logical. For example, the main cabbage production areas in Nepal are rocky high altitude slopes, classified as "not suitable for agriculture" by western planners.

Over time variants of GEOMOD have been developed (see website of Gil Pontius at Clark University) that can use many different properties of the environment (e.g., distance from roads or cities, soil types, and so on) that give the option of undertaking much more sophisticated assessments and predictions of land use change. There are a number of good chapters in [1, 16], and that use GIS and related spatial analysis techniques to examine geographical aspects of development and development possibilities, often while paying especial attention to scale issues. All of these chapters show the incredible role that geographical analyses linked with computers now play in virtually every aspect of examining development issues.

21.9 Predicting Net Economic Output as a Function of Land Type

All land does not have the same capacity for economic production, and this is especially true when specific uses are examined. For example, only about 19 percent of the total land area of Costa Rica was flat and fertile enough to be utilized for any use, including specifically row crop agriculture, which would be likely to cause irreparable damage if applied to other land categories (in other words if the land was too steep, then erosion would destroy the potential for production in a relatively short time). Another 9 percent of the land was suitable for pastures and another 16 percent for tree crops such as coffee, which causes less erosion because of its continuous cover. The rest of the country, more than 56 percent, should have no human use at all except for forestry that would maintain tree cover. In fact as of about 1990, far more than 56 percent of the country has been developed for agriculture, pastures, or urban areas. More recently much of this steep land has been reverting to forest as the futility of its economic development is increasingly clear.

Farmers and many other humans are well aware of what land is best to use for various purposes and tend to use the best land first, as is represented by the farmer's choices given in the above example for GEOMOD. Thus over time the land available for development tended to be of poorer and poorer quality, as represented, for example, in the pioneering work of David Ricardo. What this means for development is that average values of, e.g., crop production cannot be used to project what the yields might be for some development project. For example, coffee can be grown anywhere in Costa Rica. But high-quality coffee, of which Costa Rica has some of the best, requires very explicit environmental conditions (e.g., precipitation, temperature, soil, and so on) to get high yields, which tend also to mean best quality coffee beans. We found that for Costa Rica as of 1990 nearly all of the land that was best for growing coffee already had it growing there (or was covered by urbanized areas) and that if there were to be increased coffee production yields would probably be less or else more energy intensive than the average of what was occurring already. This is an example of what has been called, variously, diminishing returns to investment or declining (energy or other) return on energy investment as the best resources are used We found, quite remarkably, that for most crops any increase in area of land cropped would produce an instantaneous reduction in yield per hectare, as the land being used for production would be, on average, of lower quality. In any land use model, we have to make sure, however, that the decision rules that we put in the model are rules that farmers actually follow. This generally implies to run interviews and surveys in the field. One of the best ways to challenge and test our hypothesis is to go in the field and talk to farmers.

21.10 Assessing the Energy and Other Cost of a Development Scheme

If there is an economic plan for development, then the next step is to assess the energy, material, and other resource requirements for such a project. While this can be an extremely difficult and comprehensive issue and there is not yet a clear-cut formula for how to undertake it as we discussed above, a recent computer program derived to examine the material costs of any development project, one that we think is very good, is being developed in Italy by Sergio Ulgaldi and others at the University of Siena, Italy. Thus if we have a list of, e.g., materials required for a development project, then we can assess the most important aspects of their use rather straightforwardly. The user simply puts in dollar amounts to be spent for different development categories according to the spreadsheet provided, and the results are then printed out, a far cry from the old days of undertaking such calculations by hand as we used to do.

21.11 Include Social Assessments

As we stated in step one, many of the issues that are most important to people interested in development are of course social and economic in nature. There is no easy formula for integrating the biophysical and the socio-economic approaches, although much can be undertaken with an open mind, a willingness to work outside of one's own discipline, and, perhaps most useful, an ability to find and work with others from other disciplines. It is worth noting persistent attempts by economists to put a dollar value to "social capital," just like they do with the environment (an enterprise that we believe is seriously flawed and doomed to fail). Many of the chapters in [1, 16] are especially good at attempting to integrate biophysical and socio-economic approaches, and it is almost impossible to list specific chapters as most do in fact integrate both sciences.

21.12 Construct a Comprehensive Simulation of the Future and Make the Right Decisions!

A final step in undertaking a thorough assessment of the biophysical possibilities and constraints of a region is to examine alternative future environments in which one's decisions might be played out. Prospective analysis plays a fundamental role in shaping the development of a country. However it is poorly done at best, policy makers having to juggle with too many parameters and being forced to use shortcuts, which opens the door to misconceptions and prejudice, wrong interpretation of the data, and shortsighted emergency measures. In *The Art of the Long View*, Swartz [23] describes the critical role of scenario analysis for positioning ourselves properly into the future. Scenarios are not predictions or forecasting: they are "vehicles for helping people to learn, alternative images of the future, to change the managerial view of reality."

At the core of prospective analysis, one can easily imagine an environment to run and discuss comprehensive simulations of the future, e.g., based on the previous three steps. It can contain some or all of the entities included above plus whatever other elements the user feels appropriate, including elements of neoclassical economic analysis, and the results can be compared or by the right person even integrated! Again our example of this approach is given in the CD that is included in [1]. We believe especially in the development of good graphics and real-time simulations for communication to stakeholders and hold up the above CD as an example. Although many people are extremely suspicious of any such simulation models, we think that formalizing one's knowledge and assumptions through modeling is a critical approach that needs to be undertaken much more with the decision-makers of the developing countries in the future.

We must also face the fact that whatever good we might be able to do with the approach that we advocate can be undermined, like anything else, by the corruption and unresponsiveness of government in much of the developing (and developed) world. We have no magic solution to this either, although we are confident in the positive impact of a neutral and transparent scientific approach. But the main problem that we scientists face is that we are not very good at communicating our results to the public and therefore we have limited influence on the decisions that affect our society. This is where good computer graphics showing to the general populace the past and projected future aspects of their economies and environments as a function of whatever policies are implemented can be key. In fact we believe that if well done political debates about the future might be carried out with the aid of good computer simulations and visualizations shown on national television! We often think while watching political debates that it would be very interesting if the promises of the candidates were subject to modeling reality checks (i.e., testing of politicians hypotheses) to see what was in fact possible and at what cost! Beaulieu in [16] gives one example of a fairly successful application of science to politics.

21.13 Make the Right Decisions

Most people who are involved with such a comprehensive analysis are interested in implementing the results in what is normally called policy. Of course that can be an extremely difficult process, but if you have worked with the right people from the start, it will be possible to actually make better decisions. So it is important to involve decision-makers from the beginning. From them (and ideally from the general effected populace as well) the scientist or economist can get a much clearer idea of desired ends (which might be quite different from what the scientist or economist assumes). In turn the decision-maker can learn to have a systemic, longer-term perspective for their country.

21

"Hybrid" forums where scientist and citizens meet and exchange views are ideal for social-technical debates and the education of each. Again the use of dynamic graphs that can convey to the user possible futures as a function of policy today can be very useful. Finally with the new insights gained from the entire process given above, reexamine if and where conventional economics has failed and propose amendments to neoclassical economics-based policy or develop an entire new perspective based on the analyses we have given above. It is a big charge to develop an entirely new economics, but we think it critical, and what we have here is a formal start. And of course throughout the entire process of undertaking biophysical economic assessments and plans, the scientific method must be used, theories need to be advanced in a way consistent with first principles, hypotheses need to be generated and tested, and so on. The final arbitrator of the correctness of our analyses is not whether this or that theory is the basis for our efforts but whether our predictions and policy prescriptions come to pass. This closes the loop on what is our basic wish: to bring the scientific method to our development economics.

Questions

1. Explain some virtues of the process of visualization of model output (as was done, e.g., for Costa Rica).
2. Distinguish among "environmental economics," "ecological economics," and "biophysical economics."
3. What is an ecological footprint? How does that relate to biophysical economics?
4. What is emergy analysis? How does it differ from energy analysis?
5. Give one example where biophysical economic, footprint, and energy analyses give substantially the same answer.
6. Give five steps that can be followed in developing a biophysical analysis.
7. How can social, political, and economic elements be incorporated into a biophysical analysis?
8. What kinds of issues might one want to gather data on in a biophysical assessment?
9. What is a simple way of translating a simple growth rate into a doubling time? For example, the United States had 300 million people growing at 1 percent a

year in about the year 2000. If this 1 percent a year growth rate continues, when would the United States have 600 million people? How old would you be then if you were still alive?
10. What are time series data? How do they help us to understand biophysical economics?
11. What kind of corrections need to be made for raw economic data (e.g., GDP) when examining data over time?
12. What is the Gini index? How does that help to put a more nuanced perspective on, for example, GDP data?
13. What are a few important considerations in how imports, exports, and their difference might influence our economic policies?
14. How does a prediction of land use change understand possible economic possibilities? How does that relate to land quality?
15. What are some of the pitfalls that await even the best possible plan that one might develop? How can citizen involvement assist in that process?

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