

## Sustainable Economic Development

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Three issues are central to an examination of sustainable economic development and public policies to foster this development:

1. Who speaks for the environment and future generations?
2. How rosy is the future?
3. Are environmental resources unique in production?

The first issue is at the heart of the sustainability debate. What will future generations desire? What do we mean by "environmental quality?"

The people currently alive can articulate what they regard as good or bad futures, but we have no idea what future generations will desire. For example, suppose that your great, great grandfather, at great sacrifice, preserved the best spot for a privy for your generation. The point is that technologies change and what was a wonderful gift at one time becomes useless at another. This doesn't mean that the current generation has no obligation to preserve opportunities for future generations, but it does mean that we must examine our sacrifices in view of likely changes in technology, population size, and tastes.

Environmental quality is a complicated vector, not a simple scalar. Acidified lakes in northern New York are clear and inviting, like swimming pools. In contrast, "living" lakes have muddy bottoms and are filled with plants and animals of varied size, including harmful bacteria and leeches. How hard should we work to preserve harmful bacteria and leeches? How much effort should we put into preserving wetlands that are breeding grounds for mosquitoes and disease?

We all desire environmental quality, but few of us agree on what constitutes quality. One extreme would be to minimize the environmental footprint of human actions. The other extreme would be to shape the environment to offer more services, e.g., drain swamps to prevent disease, clear brush to make hiking trails, and stock trout in lakes to provide better fishing. Still more extreme are those who regard ultimate environmental quality as a place completely undisturbed by humans - no human access allowed. As extreme in the other direction are those who regard the wilderness as attractive principally because it gives space for motorized craft, such as snow mobiles, four wheel drive trucks, and speed boats. The point is that there is no agreement about what constitutes environmental quality.

The attractiveness of our future, issue 2, is an unstated assumption in most discussions. Pessimists regard the future as spiraling ever downward, with environmental quality and the well-being of future generations continually declining [U. S. Department of Commerce, 1980, Ehrlich & Ehrlich, 1981]. If so, major action is needed now to prevent this disaster. Optimists see an improving future that gives humans more opportunities and choices [Simon & Kahn, 1985, Simon, 1995]. Will those living in 100 years have a small fraction of the income we currently enjoy or will they be richer than we are?

If the future generations can be expected to be worse off than we are, we need to consider making large sacrifices in order to increase their welfare. We need to preserve more natural resources and save more to increase the capital stock. In this view, the current generation is unwilling to recognize the perilous state of future generations and unwilling to make the sacrifices necessary to preserve the lifestyles of future generations.

If future generations can be expected to be richer than we are, additional sacrifices today would make future generations still better off, but there is little reason to make these sacrifices. Why should I lower my consumption so that people alive in 100 years will have three times my income, rather than twice my income?

Differences in how rosy the future will be are fundamental to discussions about the future. Unfortunately, these expectations about the future are rarely stated. Nonetheless, they are perhaps the primary reason for the different proscriptions concerning the future.

The substitutability of resources, issue 3, is important: Every barrel of oil and every ton of rich iron ore used by the current generation means less resources for future generations. If environmental resources are unique, the only sustainable economy is one that uses no nonrenewable resources. Thus, the path to sustainability requires that we phase out our consumption of nonrenewable natural resources as quickly as possible.

If environmental resources are not unique in production, the classical economic view is that society should ensure that the value of resources passed on to future generations should be as great as our generation received. I will elaborate below, but in this view, the economy is sustainable as long as the value of resources passed on to future generations is at least as great as that given to the generation.

## Managing A Modern Economy for Sustainability

A modern economy, such as that of the United States or the Netherlands, is large and complicated, with many interactions. The economy is too large and complicated for a central authority to be able to control it in detail, as the Soviet Central planners attempted to do. In a market economy, no one is responsible for making sure that there is bread and milk in the supermarket for consumers or indeed for insuring that consumers don't go hungry for weeks because of production or delivery problems. No one is responsible for ensuring that adequate supplies of coal, petroleum, and other fossil fuels are available for production and consumption.

Modern economic theory could be thought of as a way of decomposing the complicated structure of an economy so that workers, firms, and consumers who are each trying to do the best for themselves wind up doing what is best for the economy. Prices are the signaling devices by which consumers indicate that they want more of some good or service; they are a way of signaling producers of products and raw materials to increase production. If there is insufficient petroleum at the current price, price rises signaling consumers to purchase less and producers to increase the quantity they are offering. If petroleum resources are being depleted so that petroleum will be much more valuable in the future, the current price will rise to reflect the future high prices.

Assuming the economy is competitive and there are no externalities, economic theory shows that a competitive market produces an efficient outcome. When markets exist for all future goods and services, the framework can be extended to show that a market will account for resource production and use in the future, bringing about efficient outcomes over time.

Three major challenges have arisen to the desirability of this competitive outcome. The first is that markets must be competitive. Both the USA and the European Union have antitrust policies to preserve and enhance competition.

The second challenge comes from externalities, both positive and negative. Environmental discharges are an example of a negative externality. Without ways of charging firms for the environmental discharges, the market will not produce an efficient outcome. Both the European Union and the USA have erected an elaborate array of environmental laws and regulations to internalize this externality.

The third challenge arises from the fact that markets do not exist for goods and services in future markets. I cannot purchase one million barrels of crude oil for delivery in Pittsburgh on June 1, 2050. Of greater importance, I cannot purchase a contract that, if petroleum costs more than \$100 per barrel in 2050, I will have a technology available to me that gives me the services I desire without using petroleum.

I leave the first of these difficulties to the U.S. Department of Justice Antitrust Division, the U.S. Federal Trade Commission and their European Union counterparts. Challenges two and three are my focus here.

### The Role of Life Cycle Analysis in Environmental Regulation

The landmark legislation for environmental protection is the 1970 Clean Air Act which defined a central role for the U.S. federal government. The newly created Environmental Protection Agency was given the mission of getting emissions standards for a range of pollutants. Subsequent legislation expanded EPA's role to setting discharge standards for a wide range of pollutants in water and solid waste.

Both for a regulatory agency and for the firms being regulated, selecting an approach to meeting the standards control technology is difficult. Decisions, especially those concerning the environment, have wide ramifications and unexpected consequences. For example, installing flue gas desulfurization equipment on a coal burning power plant results in more energy per kilowatt hour. In a world concerned with resource depletion and greenhouse gas emissions, the lower efficiency is an unfortunate consequence.

In selecting a technology, design, or material, we need to know the life cycle implications of the alternatives - the implications for resource and energy use and for environmental discharges from the extraction (or growing) of the material through its production, use, and recycle/disposal.

Producers strive to lower their production costs in choosing among materials, designs, and capital equipment. Market prices reflect only private costs and demand. Social costs, such as environmental discharges, enter principally through regulation. For example, the price of steel reflects the demand for steel and the cost of making it, including the ore, coal and coke, labor, and capital. The costs will also reflect environmental regulations. However, if environmental regulations are too lax or too stringent, are not enforced uniformly, or do not cover important areas, prices will not reflect social costs.

Current market prices reflect the scarcity of raw materials over the next decade or so. High interest rates mean that material scarcity a century or more in the future will have almost no effect on current prices. Since greenhouse gas emissions are an externality, they are not reflected in current prices.

The 1970 Clean Air Act deals with externalities by a centralized, command and control approach. EPA is assigned the task of setting detailed emissions standards for producers in each industry based on available control technology and environmental problems. Defining "best available control technology," "new source performance standards" and the other emissions regulations for each industry have proven to be a difficult, controversial task.

The 1990 Clean Air Act tried a different approach to regulating sulfur dioxide emissions. Congress decided to experiment with a market based approach. The decided on the total amount of emissions that would be allowed, allocated these emissions among the electricity generating plants, and then allowed each plant to sell some of its "allowances" if it reduced emissions more than the stipulated amount or to buy allowances if reducing emissions was extremely costly. This market based approach resulted in saving about 2/3 of the estimate abatement cost and achieve the reductions more quickly than mandated by law.

The success of sulfur dioxide allowances increased support for a much greater use of market mechanisms in achieving environmental goals. However, at present, prices contain only a distant aspect of the social costs of depleting stratospheric ozone, contributing to air pollution and water pollution or otherwise harming human health and the environment. Command and control regulation does affect the prices of products and materials through the costs of control. However, the current system is sufficiently imperfect that EPA regulations are not close to optimal levels. As a result, the resulting control costs can either overstate (as for Superfund) or understate (as for materials that contribute to indoor air pollution) the social costs of improving environmental quality.

Since market prices don't reflect social costs, the market cannot perform its decomposition function properly. This means that a separate analysis is required of the life cycle implications of choosing among alternative materials, designs, processes, and recycling/disposal options.

EPA and the Society of Environmental Toxicologists and Chemists (SETAC) developed the current method for life cycle analysis. It is a straight forward analysis of production processes beginning with the production of the product of interest. It then goes backward to the most important processes that provide inputs to the product production. Perhaps the most important step in the analysis is to draw a boundary around the problems to decide what will be considered. This approach has been criticized as inadequate and arbitrary [Portney, 1993].

The Carnegie Mellon Green Design Initiative has developed a different approach [Lave et al., 1995, Hendrickson et al., 1997]. We take the input-output table for the United States and append to it environmental and raw material vectors to describe the energy and other inputs to each process and the environmental discharges that result. This approach allows us to avoid setting arbitrary boundaries on the problem. This is a general equilibrium economic model and so all of the inputs and all of the environmental discharges, both direct and through supplies, are calculated.

One application of this model is to the requirement of the California Air Resources Board that a specified proportion of new cars sold, beginning in 1998, had to be zero emissions cars. CARB is concerned with reducing emissions of the gases that form ozone over much of California. A zero emissions car would lower air pollution emissions because it has no tailpipe.

The cars designed to meet the CARB requirement are battery powered. In particular, the cars currently marketed contain 500 kg or more of lead-acid batteries. The cars have no tailpipe, but require electricity to recharge the batteries. While electricity generation produces air pollution, a modern electricity generation plant with its stringent environmental controls will produce less pollution than the comparable number of gasoline fueled cars that it replaces.

However, each car has 500 kg or more of lead acid batteries. A large amount of lead must be mined, smelted, made into batteries, and then must be recycled into new batteries. We calculate that the most advanced electric car, General Motors' EV1, would result in much more lead being discharged into the environment, per vehicle mile, than a comparable internal combustion engine car burning gasoline with tetraethyl lead [Lave et al., 1995]. In a second analysis, we calculated that half a million EV1s in Southern California in 2007 would lower peak ozone from 200 ppb to 199 ppb, a reduction too small to be measured reliably [Lave et al., 1996]. At the same time, half a million EV1s would increase total lead use in the USA by 20%, presumably increasing total lead discharges by 20%. Although we did not make the direct calculations about health implications, it seems evident that a 1 ppb reduction in peak ozone in one region is much less of a health benefit than a 20% increase in lead discharges throughout the USA.

This calculation illustrates the importance of a life cycle framework in considering decisions concerning alternative designs, materials, processes, and recycle/disposal decisions.

#### Sustainable Development: The Role of Technology

The Bruntland Commission defined sustainable development to mean satisfying current needs without diminishing the ability of future generations to satisfy their needs. This statement is wonderfully crafted to cover a wide range of meanings, depending on the goals of the listener. This is perhaps the principal reason why there has been such wide spread agreement on satisfying the goal: Without further definition, it is a principle largely without content.

Some environmentalists take a static view of technology and economics in interpreting the phrase. If one assumes that one cannot depend on technology improving and that people in the future will have the same tastes as those alive today, the USA must drastically cut consumption by ending all use of nonrenewable resources. The implications of this view are that all countries, both rich and poor must restructure their economies and curtail consumption. Furthermore, current population is too large for sustainability.

Some industrialists take a dynamic view of technology and resources.

With rapidly advancing technology, resources could be stretched to provide much more consumer goods with less damage to the environment. In this world, we can be less concerned about using up raw materials since technology will find ways of using less of the scarce resources and will find substitute resources. Thus, curtailing US economic activity is needlessly painful. A better way to achieve sustainability is to develop new technology to accomplish the goal.

Important examples support each of these views. On the one hand, soil loss in the USA from cultivating unsuitable areas combines with the damage from strip mining and the superfund sites resulting from thoughtless manufacturing to produce an unattractive future. On the other hand, Current cars have twice the fuel economy of 1974 models and computing is millions of times more efficient than it was 40 years ago.

One's individual interpretation of "sustainability" leads to a wide range of policies. Technological-economic optimists can insist that the government keep its hands off the economy, since a free market will produce technology and resources for sustainability. Optimists with a more interventionist bent might insist on increased expenditures for R&D to increase the efficiency of resource utilization. Interventionist pessimists might insist on government programs to promote zero population growth and a reduction of consumption among the rich. Less interventionist pessimists might advocate educating consumers to want fewer products and services and to share wealth with poor countries.

We have no way of knowing whether future technology will require only a tiny proportion of today's resources. Whenever the price of some raw material has increased sharply, alternative supplies have been supplied within a short period of time. For example, a vast amount of oil was discovered after the 1973 OPEC oil embargo and subsequent price increase. An optimist might have no hesitation in continuing to increase the use of petroleum. A pessimist might want to see the substitute resources and new technology first.

The point is that viewing sustainability in static terms is too narrow and limited. Great progress has been made in getting more of the goods and services that people desire out of raw materials whose price has increased. Assuming that no further technological progress will occur is an extreme assumption. However, assuming that technology will become available when desired is an equally extreme assumption. Investors in the USA and other nations demand a high return on their investments. In practice, this means that they and the companies they own have extremely short time horizons: If we won't run out of petroleum in the next few years, we don't worry about the problem today. This viewpoint neglects the time required to develop viable new technologies or put them into place.

Perhaps the one point of agreement is that technology is the key to the future. Society could suffer a large loss if the technology is not available when needed.

#### A Neo-Classical Economic Growth Model

Elena Shewliakowa, Eduardo Vergara and I [ Shewliakowa et al., 1997] have been exploring sustainable development in a neoclassical growth model. This highly stylized model is of a single nation that has a stock of cheap resources, a level of technology for utilizing available renewable sources, and a level of productivity in accomplishing R&D. This is a simple world where a single commodity is produced with labor and energy. People consume the commodity; however, they can decide how much of the labor force to devote to R&D. R&D workers don't contribute to current production and so each worker switched from production to R&D lower the total consumption of all workers. Thus, switching workers from production to R&D sacrifices current consumption for better technology that will increase production (and consumption) in the future.

Energy is needed in both the production and R&D activities. The inexpensive oil stock increases production - while it lasts. When the oil is gone, the economy will have only solar energy. The current technology for using solar energy is not efficient. However, R&D can make the technology better, eventually increasing the efficiency of solar energy to the point where productivity is as high as with oil.

In our model, people must decide how much of their consumption to devote to R&D. If they devote too little, the technology for using solar energy will still be primitive when the oil runs out and their consumption level would decline precipitously. However, that event is in the future, long after the current generation has died. Thus, the current generation could decide that this is not their problem and do no R&D. At the other extreme, they might decide to cut their consumption to the subsistence level and switch almost all workers to R&D.

The model produces interesting results. There are two sustainable futures. One path has low consumption based on inefficient technology for using solar energy. The other path has high consumption based on efficient use of solar technology.

A nation with large stocks of cheap oil and high R&D productivity (USA) will be able to develop excellent technology for using solar energy with hardly any sacrifice in current consumption. A nation with no oil reserves and little ability to do R&D (Namibia) has low income initially because it has little oil. Since it cannot afford to allocate many workers to R&D, and since workers are not productive at R&D, the sustainable path is at this low consumption level.

More interesting are nations with a moderate level of oil and moderate R&D productivity (Great Britain). Such a nation could decide to have high consumption today, leaving future generations with the choice of curtailing their consumption stringently, or again deciding to let the future generations fend for themselves. If each generation decides to allocate few workers to R&D, their consumption will be high until the oil runs out. When the oil is gone, the sustainable path will be at a low consumption level because it is based on primitive solar technology.

Nations willing to sacrifice a great deal so that future generations will be better off can reach the high sustainability path with little oil. Such a nation could lower current consumption, devoting all possible effort to R&D (post war Japan).

For market economies, our willingness to sacrifice for the future is indicated by the amount of income that is saved and invested for the future. The greater is savings, the lower will be the interest (discount) rate. Thus, societies, that care little about the future, will have high discount rates and low savings rates. The USA savings rate is very low, both in comparison with our historical savings rates and with other nations. Americans don't appear to be willing to sacrifice for the future. However, Technology is advancing rapidly in the USA, leaving me optimistic about the future.

#### Modeling the Role of Uncertainty

Policy making on energy conservation and greenhouse gas emissions tends to be paralyzed by uncertainty. What are the stocks of petroleum and natural gas that can be produced at low costs? What is the quantitative effect of increasing concentrations of greenhouse gases and how bad will the resulting climate change be for people and the environment?

For a decade, Europeans have advocated the "precautionary principle" in dealing with this uncertainty: When the world is at risk, don't take chances. Americans have been much more optimistic about the future

Making decisions under uncertainty has received major attention in the fields of decision theory and game theory. We might think about greenhouse warming as a game against nature [Lave & Dowlatabadi, 1993]. Humans select a policy that determines the concentration of greenhouse gases. Then nature decides on the amount of climate change and ensuing disruption. In this framework, Europeans are assuming that nature will be malevolent, choosing a bad outcome. If so, humans should employ a "minimax" strategy of minimizing the maximum loss - choosing the strategy that gives the smallest loss, even when nature is malevolent.

The opposite assumption is that nature is benevolent, showering gifts on humans. If nature were conceived to be accommodating, we would choose a strategy that assumes that nature will move to make the outcome as good as possible for humans.

Finally, we could decide that nature is indifferent to humans, employing a random strategy: If so, nature chooses outcomes using a probability distribution. In this model, we would pick the strategy that minimized expected cost/maximized expected benefit.

The precautionary principle is equivalent to a minimax strategy. Americans are not so pessimistic as Europeans and tend to favor a strategy that minimizes expected cost. The expected cost criterion leads to quite a different strategy than the minimax criterion. Thus, the difference between Europeans and Americans is not so much in their understanding of the greenhouse effect and its implications. Rather the difference is due more to their method of making decisions under uncertainty.

#### Summary

I have discussed several aspects of sustainable development, beginning with the three fundamental issues: 1. Who speaks for the environment and future generations?

2. How rosy is the future?

3. Are environmental resources unique in production?

Answering these questions is inherently difficult.

The second topic was an examination of economic theory as giving a decomposition of the economy such that a free market can produce outcomes as efficient as the best central planner can. However, the decomposition runs afoul of the assumption that externalities cannot be present. Internalizing externalities, such as environmental pollution, has been done by command and control regulation. Market mechanisms, such as effluent fees and cap and trade schemes provide more efficient mechanisms for controlling the externalities. The experiment with trading allowances for sulfur dioxide emissions showed that these mechanisms could achieve the goal at much less cost and more quickly.

In order to have efficient regulation or to set effluent fees, decision makers need to know the full life cycle implications of a decision. For example, I commented that California's requirement for zero emissions cars likely harms environmental quality by substituting a large amount of lead discharges to the environment for a tiny reduction in ozone concentrations. I described a better tool for calculating the life cycle of a product, process, or material.

Sustainable consumption paths depend on the level of renewable resources and the technology for using them. I described a neo-classical growth model that examined the interrelationships among the endowment of fossil fuels, the ability to accomplish R&D, and the willingness to sacrifice current consumption in order to improve the well-being of future generations.

Finally, I discussed the role of uncertainty in making decisions about greenhouse policy. The differences between American and European policies on greenhouse policy are more closely related to their view about what to do under uncertainty than their perceptions of the seriousness of the problem.

Although long term environmental issues are difficult to model and put into policy analysis, there are some helpful approaches and tools that have been developed.

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