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Can the Supply of Natural Resources—Especially Energy—Really Be Infinite? Yes!

> A professor giving a lecture on energy declares that the world will perish in seven billion years' time because the sun will then burn out. One of the audience becomes very agitated, asks the professor to repeat what he said, and then, completely reassured, heaves a sign of relief, "Phew! I thought he said seven million years!"
>
> *(Sauvy 1976)*

> [My economic analyses rest on] some principles which are uncommon, and which may seem too refined and subtile for such vulgar subjects. If false, let them be rejected. But no one ought to enter a prejudice against them, merely because they are out of the common road.
>
> *(David Hume,* Essays, *1777 [1987])*

> [I]t is necessary for the very existence of science that minds exist which do not allow that nature must satisfy some preconceived conditions.
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> *(Richard Feynman,* The Character of Physical Law, *1994)*

> Few arguments are more dangerous than the ones that "feel" right but can't be justified.
>
> *(Stephen Jay Gould,* The Mismeasure of Man, *1981)*

CHAPTER 2 showed that natural resources, properly defined, cannot be measured. Here I draw the logical conclusion: Natural resources are not finite. Yes, you read correctly. This chapter shows that the supply of natural resources is not finite in any economic sense, which is one reason why their cost can continue to fall indefinitely.

On the face of it, even to inquire whether natural resources are finite seems like nonsense. Everyone "knows" that resources are finite. And this belief has led many persons to draw unfounded, far-reaching conclusions about the future of our world economy and civilization. A prominent example is the *Limits to Growth* group, who open the preface to their 1974 book as follows.

> Most people acknowledge that the earth is finite. . . . Policy makers generally assume that growth will provide them tomorrow with the resources required to deal with

> today's problems. Recently, however, concern about the consequences of population growth, increased environmental pollution, and the depletion of fossil fuels has cast doubt upon the belief that continuous growth is either possible or a panacea.[1]

(Note the rhetorical device embedded in the term "acknowledge" in the first sentence of the quotation. It suggests that the statement is a fact, and that anyone who does not "acknowledge" it is simply refusing to accept or admit it.) For many writers on the subject, the inevitable depletion of natural resources is simply not open to question. A political scientist discussing the relationship of resources to national security refers to "the incontrovertible fact that many crucial resources are nonrenewable."[2] A high government energy official says that views that "the world's oil reserves . . . are sufficient to meet the worlds' needs" are "fatuities."[3]

The idea that resources are finite in supply is so pervasive and influential that the President's 1972 Commission on Population Growth and the American Future (the most recent such report) based its policy recommendations squarely upon this assumption. Right at its beginning the report asked,

> What does this nation stand for and where is it going? At some point in the future, the finite earth will not satisfactorily accommodate more human beings—nor will the United States. . . . It is both proper and in our best interest to participate fully in the worldwide search for the good life, which must include the eventual stabilization of our numbers.[4]

The assumption of finiteness indubitably misleads many scientific forecasters because their conclusions follow inexorably from that assumption. From the *Limits to Growth* team again, this time on food: "The world model is based on the fundamental assumption that there is an upper limit to the total amount of food that can be produced annually by the world's agricultural system."[5]

The idea of finite supplies of natural resources led even a mind as powerful as Bertrand Russell's into error. Here we're not just analyzing casual opinions; all of us necessarily hold many casual opinions that are ludicrously wrong simply because life is far too short for us to think through even a small fraction of the topics that we come across. But Russell, in a book ironically titled *The Impact of Science on Society*, wrote much of a book chapter on the subject. He worried that depletion would cause social instability.

> Raw materials, in the long run, present just as grave a problem as agriculture. Cornwall produced tin from Phoenician times until very lately; now the tin of Cornwall is exhausted. . . . Sooner or later all easily accessible tin will have been used up, and the same is true of most raw materials. The most pressing, at the moment, is oil. . . . The world has been living on capital, and so long as it remains industrial it must continue to do so. This is one inescapable though perhaps rather distant source of instability in a scientific society.[6]

Nor is it only noneconomists who fall into this error (although economists are in less danger here because they are accustomed to expect economic adjustment to shortages). John Maynard Keynes's contemporaries thought that he was the cleverest person of the century. But on the subject of natural resources—and about population growth, as we shall see later—he was both ignorant of the facts and stupid (an adjective I never use except for the famously clever) in his dogmatic logic. In his world-renowned *The Economic Consequences of the Peace*, published just after World War I, Keynes wrote that Europe could not supply itself and soon would have nowhere to turn:

> [B]y 1914 the domestic requirements of the United States for wheat were approaching their production, and the date was evidently near when there would be an exportable surplus only in years of exceptionally favorable harvest. . . .
>
> Europe's claim on the resources of the New World was becoming precarious; the law of diminishing returns was at last reasserting itself, and was making it necessary year by year for Europe to offer a greater quantity of other commodities to obtain the same amount of bread. . . . If France and Italy are to make good their own deficiencies in coal from the output of Germany, then Northern Europe, Switzerland, and Austria . . . must be starved of their supplies.[7]

All these assertions of impending scarcity turned out to be wildly in error. So much for Keynes's wisdom as an economist and a seer into the future. Millions of plain American farmers had a far better grasp of the agricultural reality in the 1920s than did Keynes. This demonstrates that one needs to know history as well as technical facts, and not just be a clever reasoner.

Just as in Keynes's day, the question of finiteness is irrelevant to any contemporary considerations, as the joke at the head of the chapter suggests. Nevertheless, we must discuss the topic because of its centrality in so much contemporary doomsday thinking.

The argument in this chapter is very counterintuitive, as are most of the ideas in this book. Indeed, science is most useful when it is counterintuitive. But when scientific ideas are sufficiently far from "common sense," people will be uncomfortable with science, and they will prefer other explanations, as in this parable:

> Imagine for the moment that you are a chieftain of a primitive tribe, and that I am explaining to you why water gradually disappears from an open container. I offer the explanation that the water is comprised of a lot of invisible, tiny bits of matter moving at enormous speeds. Because of their speed, the tiny bits escape from the surface and fly off into the air. They go undetected because they are so small that they cannot be seen. Because this happens continuously, eventually all of the tiny, invisible bits fly into the air and the water disappears. Now I ask you: "Is that a rational scientific explanation?" Undoubtedly, you will say yes. However, for a primitive chief, it is not believable. The believable explanation is that the spirits drank it.[8]

But because the ideas in this chapter are counterintuitive does not mean that there is not a firm theoretical basis for holding them.

The Theory of Decreasing Natural-Resource Scarcity

People's response to the long trend of falling raw-material prices often resembles this parody: We look at a tub of water and mark the water level. We assert that the quantity of water in the tub is "finite." Then we observe people dipping water out of the tub into buckets and taking them away. Yet when we re-examine the tub, lo and behold the water level is higher (analogous to the price being lower) than before. We believe that no one has reason to put water into the tub (as no one will put oil into an oil well), so we figure that some peculiar accident has occurred, one that is not likely to be repeated. But each time we return, the water level in the tub is higher than before—and water is selling at an ever cheaper price (as oil is). Yet we simply repeat over and over that the quantity of water must be finite and cannot continue to increase, and that's all there is to it.

Would not a prudent person, after a long series of rises in the water level, conclude that perhaps the process may continue—and that it therefore makes sense to seek a reasonable explanation? Would not a sensible person check whether there are inlet pipes to the tub? Or whether someone has developed a process for producing water? Whether people are using less water than before? Whether people are restocking the tub with recycled water? It makes sense to look for the cause of this apparent miracle, rather than clinging to a simple-minded, fixed-resources theory and asserting that it cannot continue.

Let's begin with a simple example to see what contrasting possibilities there are. (Such simplifying abstraction is a favorite trick of economists and mathematicians.) If there is only Alpha Crusoe and a single copper mine on an island, it will be harder to get raw copper next year if Alpha makes a lot of copper pots and bronze tools this year, because copper will be harder to find and dig. And if he continues to use his mine, his son Beta Crusoe will have a tougher time getting copper than did his daddy, because he will have to dig deeper.

Recycling could change the outcome. If Alpha decides in the second year to replace the old tools he made in the first year, he can easily reuse the old copper and do little new mining. And if Alpha adds fewer new pots and tools from year to year, the proportion of cheap, recycled copper can rise year by year. This alone could mean a progressive decrease in the cost of copper, even while the total stock of copper in pots and tools increases.

But let us for the moment leave the possibility of recycling aside. Consider another scenario: If suddenly there are not one but two people on the island, Alpha Crusoe and Gamma Defoe, copper will be more scarce for each of them this year than if Alpha lived there alone, unless by cooperative efforts they can devise a more complex but more efficient mining operation—say, one man getting the surface work and one getting the shaft. (Yes, a joke.) Or, if there are two fellows this year instead of one, and if copper is therefore harder to get and more scarce, both Alpha and Gamma may spend considerable time looking for new lodes of copper.

Alpha and Gamma may follow still other courses of action. Perhaps they will invent better ways of obtaining copper from a given lode, say a better digging tool, or they may develop new materials to substitute for copper, perhaps iron.

The cause of these new discoveries, or the cause of applying ideas that were discovered earlier, is the "shortage" of copper—that is, the increased cost of getting copper. So increased scarcity causes the development of its own remedy. This has been the key process in the supply of natural resources throughout history. (This process is explored for energy in chapter 11. Even in that special case there is no reason to believe that the supply of energy, even of oil, is finite or limited.)

Interestingly, the pressure of *low* prices can also cause innovation, as in this story:

> [In the] period 1984 to 1986 . . . the producer price of copper hovered around 65 cents per pound. In terms of constant dollars, this was the lowest price since the great depression of the 1930s. . . . [S]ome companies . . . analyzed what needed to be done to be profitable even if the price of copper remained low. . . .
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> Major copper companies have found ways of reducing their costs. Phelps Dodge . . . will improve the efficiency of its transportation of rock by use of computer monitoring and by installing an in-pit crusher. . . . [It] has improved the efficiency of its copper concentration process by employing analytic instrumentation, including x-ray fluorescence. The most effective move . . . has been to install equipment that permits inexpensive . . . production of pure copper from leachates of wastes and tailings.[9]

Improved efficiency of copper use not only reduces resource use in the present, but effectively increases the entire stock of unused resources as well. For example, an advance in knowledge that leads to a 1 percent decrease in the amount of copper that we need to make electrical outlets is much the same as an increase in the total stock of copper that has not yet been mined. And if we were to make such a 1 percent increase in efficiency for all uses every year, a 1 percent increase in demand for copper in every future year could be accommodated without any increase in the price of copper, even without any other helpful developments.*

* Baumol compared a reasonable expected increase in the rate of productivity and a reasonable expected increase in population and calculated that the stock of resource services would grow faster than the demand, suggesting that resources would be available indefinitely (1986).

Discovery of an improved mining method or of a substitute such as iron differs, in a manner that affects future generations, from the discovery of a new lode. Even after the discovery of a new lode, on the average it will still be more costly to obtain copper, that is, more costly than if copper had never been used enough to lead to a "shortage." But discoveries of improved mining methods and of substitute products can lead to lower costs of the services people seek from copper.

Please notice how a discovery of a substitute process or product by Alpha or Gamma benefits innumerable future generations. Alpha and Gamma cannot themselves extract nearly the full benefit from their discovery of iron. (You and I still benefit from the discoveries of the uses of iron and methods of processing made by our ancestors thousands of years ago.) This benefit to later generations is an example of what economists call an "externality" due to Alpha and Gamma's activities, that is, a result of their discovery that does not affect them directly.

If the cost of copper to Alpha and Gamma does not increase, they may not be impelled to develop improved methods and substitutes. If the cost of getting copper does rise for them, however, they may then bestir themselves to make a new discovery. The discovery may not immediately lower the cost of copper dramatically, and Alpha and Gamma may still not be as well off as if the cost had never risen. But subsequent generations may be better off because their ancestors Alpha and Gamma suffered from increasing cost and "scarcity."

This sequence of events explains how it can be that people have been cooking in copper pots for thousands of years, as well as using the metal for many other purposes, yet the cost of a pot today is vastly cheaper by any measure than it was one hundred or one thousand or ten thousand years ago.

Now I'll restate this line of thought into a theory that will appear again and again: More people, and increased income, cause resources to become more scarce in the short run. Heightened scarcity causes prices to rise. The higher prices present opportunity and prompt inventors and entrepreneurs to search for solutions. Many fail in the search, at cost to themselves. But in a free society, solutions are eventually found. And in the longrun *the new developments leave us better off than if the problems had not arisen*. That is, prices eventually become lower than before the increased scarcity occurred.

It is all-important to recognize that discoveries of improved methods and of substitute products are not just luck. They happen in response to an increase in scarcity—a rise in cost. Even after a discovery is made, there is a good chance that it will not be put into operation until there is need for it due to rising cost. This is important: Scarcity and technological advance are not two unrelated competitors in a Malthusian race; rather, each influences the other.

Because we now have decades of data to check its predictions, we can learn much from the 1952 U.S. governmental inquiry into raw materials—the President's Materials Policy Commission (the Paley Commission), organized in response to fears of raw-material shortages during and just after World War II. Its report is distinguished by having some of the right logic, but exactly the wrong forecasts.

> There is no completely satisfactory way to measure the real costs of materials over the long sweep of our history. But clearly the man hours required per unit of output declined heavily from 1900 to 1940, thanks especially to improvements in production technology and the heavier use of energy and capital equipment per worker. This long-term decline in real costs is reflected in the downward drift of prices of various groups of materials in relation to the general level of prices in the economy.
>
> [But since 1940 the trend has been] soaring demands, shrinking resources, the consequences [being] pressure toward rising real costs, the risk of wartime shortages, the strong possibility of an arrest or decline in the standard of living we cherish and hope to share.[10]

The commission went on to predict that prices would continue to rise for the next quarter-century. However, prices declined rather than rose.

There are two reasons why the Paley Commission's predictions were topsy-turvy. First, the commission reasoned from the notion of finiteness and used a static technical analysis of the sort discussed in chapter 2.

> A hundred years ago resources seemed limitless and the struggle upward from meager conditions of life was the struggle to create the means and methods of getting these materials into use. In this struggle we have by now succeeded all too well. The nature of the problem can perhaps be successfully over-simplified by saying that the consumption of almost all materials is expanding at compound rates and is thus pressing harder and harder against resources which whatever else they may be doing are not similarly expanding.[11]

The second reason the Paley Commission went wrong is that it looked at the wrong facts. Its report placed too much emphasis on the trends of costs over the short period from 1940 to 1950, which included World War II and therefore was almost inevitably a period of rising costs, instead of examining the longer period from 1900 to 1940, during which the commission knew that "the man-hours required per unit of output declined heavily."[12]

Let us not repeat the Paley Commission's mistakes. We should look at trends for the longest possible period, rather than focusing on a historical blip; the OPEC-led price rise in all resources after 1973 and then the oil price increase in 1979 are for us as the temporary 1940–1950 wartime reversal was for the Paley Commission. We should ignore them, and attend instead to the long-run trends which make it very clear that the costs of materials, and their scarcity, continuously decline with the growth of income and technology.

Resources as Services

As economists or as consumers we are interested, not in the resources themselves, but in the particular services that resources yield. Examples of such services are a capacity to conduct electricity, an ability to support weight, energy to fuel autos or electrical generators, and food calories.

The supply of a service will depend upon (a) which raw materials can supply that service with the existing technology, (b) the availabilities of these materials at various qualities, (c) the costs of extracting and processing them, (d) the amounts needed at the present level of technology to supply the services that we want, (e) the extent to which the previously extracted materials can be recycled, (f) the cost of recycling, (g) the cost of transporting the raw materials and services, and (h) the social and institutional arrangements in force. What is relevant to us is not whether we can find any lead in existing lead mines but whether we can have the services of lead batteries at a reasonable price; it does not matter to us whether this is accomplished by recycling lead, by making batteries last forever, or by replacing lead batteries with another contraption. Similarly, we want intercontinental telephone and television communication, and, as long as we get it, we do not care whether this requires 100,000 tons of copper for cables, or a pile of sand for optical fibers, or just a single quarter-ton communications satellite in space that uses almost no material at all.[13] And we want the plumbing in our homes to carry water; if PVC plastic has replaced the copper that formerly was used to do the job—well, that's just fine.

This concept of services improves our understanding of natural resources and the economy. To return to Crusoe's cooking pot, we are interested in a utensil that one can put over the fire and cook with. After iron and aluminum were discovered, quite satisfactory cooking pots—and perhaps more durable than pots of copper—could be made of these materials. The cost that interests us is the cost of providing the cooking service rather than the cost of copper. If we suppose that copper is used only for pots and that (say) stainless steel is quite satisfactory for most purposes, as long as we have cheap iron it does not matter if the cost of copper rises sky high. (But as we have seen, even the prices of the minerals themselves, as well as the prices of the services they perform, have fallen over the years.)*

Here is an example of how we develop new sources of the sources we seek.

* Here is an example of how new developments increase the amount of services we get from a given amount of ore: Scientists have recently rediscovered the "superplastic" steel used in ancient Damascus blades. This causes a large reduction in the amount of scrap that is left over in machining parts, and hence a large decrease in the amount of material needed, as well as the amount of energy used, in metal fabrication processes (*Chemecology*, March 1992, p. 6).

Ivory used for billiard balls threatened to run out late in the nineteenth century. As a result of a prize offered for a replacement material, celluloid was developed, and that discovery led directly to the astonishing variety of plastics that now gives us a cornucopia of products (including billiard balls) at prices so low as to boggle the nineteenth-century mind. We shall discuss this process at greater length in the context of energy in chapter 11.

Are Natural Resources Finite?

Incredible as it may seem at first, the term "finite" is not only inappropriate but is downright misleading when applied to natural resources, from both the practical and philosophical points of view. As with many important arguments, the finiteness issue is "just semantic." Yet the semantics of resource scarcity muddle public discussion and bring about wrongheaded policy decisions.

The ordinary synonyms of "finite," the dictionary tells us, are "countable" or "limited" or "bounded." This is the appropriate place to start our thinking on the subject, keeping in mind that the appropriateness of the term "finite" in a particular context depends on what interests us. Also please keep in mind that we are interested in material benefits and not abstract mathematical entities per se. (Mathematics has its own definition of "finite," which can be quite different from the common sort of definition we need here.)*

* The word "finite" is frequently used in mathematics, in which context we all learn it as schoolchildren. The definition of "finite" used in this book, however, applies not to mathematical entities but rather to physical entities. Therefore, arguments about the mathematical entities and the mathematical definition of "finite" are not germane here, even though the notion of infinity may be originally of mathematical origin.

In the first edition, I wrote that even in mathematics the word "finite" can be confusing. (I appreciate a discussion of this point with Alvin Roth.) For example, consider whether a one-inch line segment should be considered finite. The *length* of a one-inch line is finite in the sense that it is bounded at both ends. But the line within the endpoints contains an infinite number of points which have no defined size and hence cannot be counted. Therefore, *the number of points* in that one-inch segment is not finite. My point, as I wrote, was that the appropriateness of the term "finite" depends upon what interests us. This paragraph elicited much criticism, and because it is not necessary to the argument, I leave it out this time.

When I wrote about a line's finiteness in the first edition, I did not intend to suggest that the supply of copper should be considered to be not finite because it could be subdivided ever more finely; however, what I wrote caused some confusion. I meant to say that if we cannot state *how to count* the total amount of a resource that could be available in the future, it should not be considered finite. But in one important sense the notion of subdivision *is* relevant. With the passage of time and the accumulation of technical knowledge, we learn how to obtain a given amount of service from an ever-smaller amount of a resource. It takes much less copper now to pass a given message than a hundred years ago. And much less energy is required to do a given amount of work than in the past; the earliest steam engines had an efficiency of about 2 percent, but efficiencies are many times that high now.

The quantity of the services we obtain from copper that will ever be available to us should not be considered finite because there is no method (even in principle) of making an apporpriate count of it, given the problem of the economic definition of "copper," the possibility of using copper more efficiently, the possibility of creating copper or its economic equivalent from other materials, the possibility of recycling copper, or even obtaining copper from sources beyond planet Earth, and thus the lack of boundaries to the sources from which "copper" might be drawn. That is, one cannot construct a working definition of the total services that we now obtain from copper and that can eventually be obtained by human beings.[14]

This is easier to see now than ever before. After centuries of slow progress and the use of mostly the familiar materials such as stone, wood, and iron, science is attaining undreamed-of abilities to create new materials. This includes syntheses of known compounds and also "materials that do not exist in nature. . . . Instead of trying to modify existing materials, scientists now are learning to assemble atoms and molecules systematically into new materials with precisely the properties they need for designs too demanding for off-the-shelf resources."[15] The first auto engine parts made of silicon and carbon—water-pump seal rings—are now being installed in Volkswagens, and engines could soon be made of silicon carbide, cutting weight and emissions in addition to replacing metals.[16] Palladium instead of platinum can now be used in auto exhaust emission systems.[17] Organic plastics can now be blended with glass to yield a material as strong as concrete but flexible and much lighter.[18] And a feasible way has been found to make heat-resistant plastics using gallium chloride.[19] Ceramics engineering is exploding with new knowledge, finally putting an end to past generations' worries about running out of metals.

Plastics are now made only from fossil fuels or oils from plants grown in fields, but researchers have recently found ways to convert such agricultural products as potatoes and corn into direct sources of plastics by inserting special plastic-producing genes into them.[20]

In light of these extraordinary developments—which continue the line of discoveries since humankind thousands of years ago found a way to convert iron into a resource by learning how to work with it—concern about running out of materials such as copper seems ever less sensible.

Consider this remark about potential oil and gas from an energy forecaster. "It's like trying to guess the number of beans in jar without knowing how big the jar is." So far so good. But then he adds, "God is the only one who knows—and even He may not be sure."[21] Of course he is speaking lightly. but the notion that some mind *could* know the "actual" size of the jar is misleading,

This sort of gain in efficiency fits with Baumol's line of thought, discussed above, that an improvement in productivity not only reduces resource use in the present, but increases the future services from the entire stock of resources.

because it implies that there is a fixed quantity of standard-sized beans. The quantity of a natural resource that might be available to us—and even more important the quantity of the services that can eventually be rendered to us by that natural resource—can never be known even in principle, just as the number of points in a one-inch line can never be counted even in principle. Even if the "jar" were fixed in size, it might yield ever more "beans." Hence, resources are not finite in any meaningful sense.

The entire notion of the nonfiniteness of resources such as copper, energy, and living space may so boggle the mind of some readers as to turn them away from the rest of the book. If this is so for you, please notice that one can reach the same practical conslusions from current data and economic theory, without making the stronger argument about infinite resources, as long as one accepts that it is silly to worry now about any implications of the proposition that energy will run out in (say) seven billion years. If the notion of finitude is quite irrelevant for you, as it is for me, please skip the rest of the discussion on the subject. But for some other, I cannot leave out discussion of the issue, because it is the basis of their thinking.

Well-wishers have advised me to "admit" that resources are limited to the capacities of the planet, thinking that this will keep me from "losing credibility." And I seem pigheaded to them when I do not follow their advice. But this is why I continue to argue that these quantities are not finite: The rhetorical difficulty is that as soon as one would "admit" that there are only (say) seven billion years of energy, some doomsters begin to work backward to argue that the sun's measurable size and rate of energy output means that the supply of energy is finite for next year. But that's physical estimate—it's not an economic definition of "energy," any more than copper atoms in the Earth's crust is a useful *economic* definition of "copper."

Objections to the notion of nonfiniteness often come from a mathematical background. Yet there is ample justification even within mathematics itself for taking the point of view that I do, and mathematical statisticians such as Barrow and Tipler affirm this. As Tipler puts it, "The laws of physics do not forbid perpetual economic growth."[22]

I continue to stand on the ground of nonfiniteness because I have found that leaving that ground leads to more bad arguments than standing on it, even though it seems so strange to many. and I doubt that many people's judgment will be affected by what I write on this particular issue. Hence there is little temptation to trim my sails to this wind, and do that which is offensive to me—to "admit" something that I do not believe is so.

But what if I am wrong? Certainly it is possible that the cosmos has a countable amount of mass/energy. How should we continue with that line of thought?

We have seen that even if energy is the relevant constraint for fabricating new kinds of "raw" materials, one would need to take into account, at the very

least, all the mass/energy in the solar system. This amount is so huge relative to our use of energy, even by many multiples of the present population and many multiples of our present rates of individual use, that the end of the solar system in seven billion years or whenever would hardly be affected by our energy use now. This should be reason enough to ignore the issue of finitude.

Even if human population and the rate of using energy and materials should increase vastly so as to controvert the previous paragraph, there is the possibility that humans will come to exploit the resources of other parts of the cosmos, which is so huge relative to the solar system as to render calculations irrelevant under any conceivable rates of growth. If so, further discussion would see frivolous.

Physicist Freeman Dyson, in his book, *Infinite in All Directions*, takes this mode of thought much further and theorizes that even if the world were to get progressively colder forever, it would be possible for human beings to adapt in such fashion as to stay ahead of the cooling; consequently, he writes, "Boiled down to one sentence, my message is the unboundedness of life and the consequent unboundedness of human destiny."[23] And physicist Frank Tipler argues, on the basis of the established body of contemporary knowledge of physics, that the ultimate constraint is not energy but rather information. Because we can increase the stock of information without limit, there is no need to consider our existence finite.* Of course these arguments are exceedingly abstract, and far from contemporary concerns. I cite these ideas not as proof that the future of humanity is not finite, but rather as showing that the doomsayers' arguments from physics that human existence is *not* finite are not consistent with a solid body of reasoning by physicists.

To restate: A satisfactory operational definition—which is an estimate—of the quantity of a natural resource, or of the services we now get from it, is the only sort of estimate that is of any use in policy decision. The estimate must tell us about the quantities of a resource (or of a particular service) that we can expect to receive in any particular year to come, at each particular price,

* The amount of knowledge would not be finite in any meaningful sense, because the stock of knowledge can grow at a faster rate than the stock of energy can decline, which would eventuate in a cushion much greater than necessary to accommodate the possible growth in human population. (I do not give the specifics of such a calculation because doing so would be a waste of time.)

In order to show that we ought to take account of finitude, one would first have to show that the previous issue—the eventual domination of knowledge rather than energy—is wrong. Then one would have to show that the probabilities of a nonfinite universe and the future exploitation of the cosmos outside the solar system are very low, then show some reasonable basis for saying that events beyond (say) a thousand or million or more years, all the way to seven billion years, would matter for our economic choices now, then show that the likelihood is low that our present understanding of the mass/energy relationship is wrong, then show that there is little likelihood that it is possible to get our needs serviced with ever-smaller amounts of energy. Without some reasonable argument about *every link* in that chain, discussion of the finitude of energy that will be available to humans seems misplaced.

conditional on other events that we might reasonably expect to know (such as use of the resource in prior years). And there is no reason to believe that at any given moment in the future the available quantity of any natural resource or service at present prices will be much smaller than it is now, let alone non-existent. Only one-of-a-kind resources such as an Arthur Rubinstein concert or a Michael Jordan basketball game, for which there are no close replacements, will disappear in the future and hence are finite in quantity.

The term "finite" is not meaningful when applied to resources because we cannot say with any practical surety where the bounds of a relevant resource system lie, or even if there are any bounds. The bounds for Crusoes are the shores of their island, and so it was for early humans. But then Crusoes find other islands. Humankind traveled farther and farther in search of resources—finally to the bounds of continents, and then to other continents. When America was opened up, the world, which for Europeans had been bounded by Europe and perhaps by Asia too, was suddenly expanded. Each epoch has seen a shift in the bounds of the relevant resource system. Each time, the old ideas about "limits," and the calculations of "finite resources" within those bounds, were thereby falsified. Now we have begun to explore the sea, which contains amounts of metallic and perhaps energy resources that dwarf any deposits we know about on land. And we have begun to explore the moon. Why shouldn't the boundaries of the system from which we derive resources continue to expand in such directions, just as they have expanded in the past? This is one more reason not to regard resources as "finite" in principle.

Why do we become hypnotized by the word "finite"? That is an interesting question in psychology, education, and philosophy. One likely reason is that the word "finite" seems to have a precise and unambiguous meaning in any context, even though it does not. Second, we learn the word in the context of simple mathematics, where all propositions are tautologous definitions and hence can be shown logically to be true or false. But scientific subjects are empirical rather than definitional, as twentieth-century philosophers have been at great pains to emphasize. Mathematics is not a science in the ordinary sense because it does not deal with facts other than the stuff of mathematics itself, and hence such terms as "finite" do not have the same meaning elsewhere that they do in mathematics.

Third, much of our daily life about which we need to make decisions is countable and finite—our salaries, the amount of gas in a full tank, the width of the backyard, the number of greeting cards you sent out last year, or those you will send out next year. Since these quantities are finite, why shouldn't the world's total possible salary in the future, or the gasoline in the possible tanks in the future, or the number of cards you ought to send out, also be finite? Though the analogy is appealing, it is not sound. And it is in making this incorrect extension that we go astray in using the term "finite."

I think we can stop here. I'm sorry to have taken up your time with this unless you were seriously worried beforehand about what will happen seven billion years from now.

Summary

A conceptual quantity is not finite or infinite in itself. Rather, it is finite or infinite if you make it so—by your own definitions. If you define the subject of discussion suitably, and sufficiently closely so that it can be counted, then it is finite—for example, the money in your wallet or the socks in your top drawer. But without sufficient definition the subject is not finite—for example, the thoughts in your head, the strength of your wish to go to Turkey, your dog's love for you, the number of points in a one-inch line. You can, of course, develop definitions that will make these quantities finite, which shows that the finiteness inheres in you and in your definitions rather than in the money, love, or one-inch line themselves. There is no necessity either in logic or in historical trends to state that the supply of any given resource is "finite," and to do so leads into error.

Someone coined the label "cornucopians" for those who believe that the natural resources are available in practically limitless abundance, to contrast with "doomsters." But the stream of thought that I represent here is not cornucopian. I do not suggest that nature is limitlessly bountiful. Rather, I suggest that the possibilities in the world are sufficiently great so that with the present state of knowledge—even without the additional knowledge that human imagination and human enterprise will surely develop in the future—we and our descendants can manipulate the elements in such fashion that we can have all the raw materials that we desire at prices ever smaller relative to other goods and to our total incomes. In short, our cornucopia is the human mind and heart, and not a Santa Claus natural environment. So has it been throughout history, and therefore so is it likely to be in the future.