ABOUT THE AUTHOR

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Common Wealth

ECONOMICS FOR A CROWDED PLANET

Jeffrey D. Sachs

PENGUIN BOOKS

Ending the Poverty Trap

Ending the trap of extreme poverty is the third great challenge of sustainable development. The central solution to ending extreme poverty is to empower the poor with improved technology so that they can become productive members of the world economy. The central problem is that the extreme poor are unable to purchase those very technologies on their own. They lack their own savings and they also lack the creditworthiness to borrow. The result is the poverty trap, in which extreme poverty keeps vital, even life-saving, technology out of the reach of the poor, and the lack of that technology keeps the poor unproductive and condemns them to continued poverty. The trap can be broken if public financing provides the poor with the technologies that they need but cannot afford. The technology raises their productivity; this increases their income, allows for savings and investment, and thus breaks the trap.

We will describe four priority areas where improved technologies are already widely used around the world but not by the extreme poor: high-yield agriculture (including improved seed varieties, chemical fertilizers, and small-scale irrigation), educational technologies (as basic as classrooms and sanitary facilities for girls, but also connectivity for distance learning), health care technologies of all sorts, and modern infrastructure (all-weather roads, rehabilitated rail lines, electricity, safe drinking water, sanitation, telecoms, and the Internet). If the poor can be empowered with these technologies, they will experience a significant rise in productivity and thereby be enabled to join the process of convergent economic growth.

Foreign assistance can be the key in this process. If well targeted toward the crucial needs—in agriculture, health, education, and infrastructure—foreign aid can provide the breakthrough financing to enable the poor to escape from poverty. Such success has occurred many times in the past, for example, in the international support for countries to fight diseases such as smallpox and measles, or to raise agricultural production through the adoption of high-yield seed varieties. We will describe at length some of these earlier successes and how the lessons from them can be usefully applied in our own time.

Will We Run Out of Resources?

Even with the best of intentions, it might seem futile to plan for a richer world with shared prosperity. After all, many key resources are necessarily depleting, with no prospect for regrowth within the time span of society. Fossil fuels, for example, were laid down hundreds of millions of years ago by the deposition of organic matter that gradually was converted into coal, oil, gas, and other fossil fuels. As we use the oil, it is running out. Perhaps there are just a few decades left until we've exhausted the world's oil stocks. This seems the stuff of nightmares, the assured collapse of our fossil fuel civilization. Similarly, in some places we are running out of "fossil" groundwater, meaning water in deep underground aquifers that is being pumped to the surface for human uses at rates vastly greater than the aquifers' natural recharge through rainwater that infiltrates into the aquifer. Are we doomed, or more precisely, is the future doomed?

Even in the face of some resource depletion, future generations can be spared a collapse of living standards. First, as we run out of one resource, say, oil, we can shift to other resources in more plentiful supply. Perhaps both are depletable, but by shifting from one to the next, we postpone the ultimate reckoning. Second, we can shift from the depleting resource (say, oil again) to a renewable resource, such as solar power. Third, we can economize on the use of the depleting resource, for example, by investing in better insulation in order to use less home heating oil.

There has been much consternation about "peak" oil, the idea that the world may be nearing the peak of total oil production and, therefore, faces a decline of oil reserves and oil production in future decades because we have discovered and already developed most or all of the world's great oil fields. The common assumption is that peak oil, if true, is a disaster: the world hitting a brick wall of oil supply just as the developing world is ramping up its demand for it. Yet the consequences would not be nearly as dire as some have suggested. We might run out of conventional petroleum in a few decades, but we have centuries left of coal and other nonconventional fossil fuels, such as tar sands and oil shale. This may seem like slight consolation, since it is hard to put coal into the gas tank. Yet chemists know precisely how to do that, using an industrial process known as Fischer-Tropsch liquefaction, which converts coal into liquid hydrocarbons such as gasoline at relatively low cost. In the long run, we need to be more concerned about the total supply of fossil fuels than with the supply of oil alone, since the fossil fuels are reasonably changeable from one to the other through known industrial processes.

The best evidence regarding the total fossil fuel supply is that we have enough for this century, even with substantial economic growth, but we will

have to rely increasingly on coal and nonconventional fossil fuels. In the most authoritative recent estimate, Hans-Holger Rogner reaches the following crucial conclusion:

> The global fossil fuel resource base is abundant and is estimated at approximately 5000 Gtoe (billion tons of oil equivalent). Compared to current global primary energy use of some 10 Gtoe per year, this amount is certainly sufficient to fuel the world economy through the twenty-first century, even in the case of drastic growth in global energy demand.

The challenge for this century will not be in the limited availability of fossil fuels, but in their safe ecological use and in the timely investments needed to ensure that the right kinds of fuels are available at the right times and places (such as the conversion from coal to liquids). For the twenty-second century and onward, there is a reasonable chance that we will need to convert massively to alternative technologies, such as solar power or nuclear power.

Fortunately, the long-term prospects for solar power are very good. The total solar radiation that reaches the Earth is about ten thousand times greater than our current commercial energy use. By harnessing that solar power, we could eventually dispense altogether with our reliance on fossil fuels. We already harness solar power in many forms: solar panels to produce electricity, the direct solar heating of water, wind power (which itself is the conversion of solar radiation into the movement of air molecules), hydroelectric power (remembering that the hydrological cycle is powered by solar radiation), and, of course, biofuels (using the products of photosynthesis). Currently, the cost of these various kinds of solar power tends to exceed most applications of fossil-fuel-based energy. With improved technologies, however, solar power will eventually compete favorably with fossil fuel power, and thereby provide a backstop technology to ensure the world's long-term energy future.

With other threatened resources (groundwater, fish, tropical forests, soil nutrients, farmland), there are usually many ways to use man-made capital to economize on the depletable natural resource under stress. Ocean fisheries can be made sustainable, for example, by the introduction of fish farms to replace open-sea fishing. The ocean is spared at the expense of increased land use (both for the fish farm and for the land to produce the fish meal). The development of high-yield seed varieties allows for a reduction of land under cultivation while still producing the same amount of food. Drought-resistant seed varieties can facilitate the reduction of water use. And the list goes on.

None of these possibilities ensures that such sustainable technologies will be adopted smoothly and at a scale necessary to avoid massive ecological and economic disruptions. Coal can be converted to liquid fuels, for example, but it can only be converted at a large scale if significant investments in Fischer-Tropsch industrial units are made in advance. Sustainable development may be achievable in theory but not reached in practice if public policies and market forces do not lead to the needed investments.

We can summarize in the following way: the world is facing enormous ecological and environmental problems, but running out of natural resources is not the right way to describe the threat. Earth has the energy, land, biodiversity, and water resources needed to feed humanity and support long-term economic prosperity for all. The problem is that markets might not lead to their wise and sustainable use. There is no economic imperative that will condemn us to deplete our vital resource base, but neither is there an invisible hand that will prevent us from doing so. The choice will be ours to make through public policy and global cooperation.

Resource Scramble or Systematic Innovation?

Despite the vast stores of energy, including nonconventional fossil fuels, solar power, geothermal power, nuclear power, and more, there is a pervasive fear of an imminent energy crisis resulting from the depletion of oil. The scramble of powerful countries to control Middle East oil or newly discovered reserves in other parts of the world, such as West Africa and the Arctic, has surely intensified, while investments in alternative and sustainable energy sources have been woefully insufficient. This is an example of a vicious cycle of distrust. The world could adopt a cooperative approach to develop sustainable energy supplies, with sustainability in the dual sense of low greenhouse gas emissions and long-term, low-cost availability. Alternatively, we can scramble for the depleting conventional oil and gas resources. The scramble, very much under way today, reduces global cooperation, spills over into violence and risks great power confrontations, and makes even more distant the good-faith cooperation to pool R & D and investments to develop alternative fuels and alternative ways to use nonconventional fossil fuels.

The Bush administration has been more consumed by the scramble rather than by cooperative global investments in a long-term future. The adminis-

tration's outlook has been dominated by the oil industry, not by a broader perspective on sustainable energy potential or global sustainable development more generally. The Iraq War has its roots in the misapplied quest of the Bush administration for U.S. energy security, though the war has only deepened the insecurity. Yet the U.S. fixation on Middle East oil goes back more than half a century to the CIA-backed coup that overthrew the prime minister of Iran in 1953 and a seemingly endless series of CIA and military misadventures since then. Hundreds of billions of dollars have been spent in military efforts to ensure the security (for the United States) of Middle East oil fields, swamping the funds that have been applied to developing long-term energy alternatives. Panic has consistently superseded good judgment and a long-term cooperative perspective.

Reinvigorating Global Cooperation

From time to time since World War II the world has cooperated on the central challenges of living together on this small planet. The American neoconservatives who have fantasized about U.S. unilateral dominance have ridiculed those who believe in global cooperation, but the truth is that when global cooperation has been tried, it has paid off brilliantly.

- Foreign aid has contributed to the economic development of Asia and Latin America through the Green Revolution of increased agricultural productivity; the control of infectious diseases, such as smallpox; the vast rise of literacy and school attendance; and much more.
- Foreign aid and global agreements have facilitated the dramatic, indeed revolutionary, dissemination of modern methods of contraception and family planning, leading to a crucial voluntary drop of fertility rates in most of the world.
- Global cooperation has produced major advances in global environmental control, most successfully in heading off the destruction of the layer of stratospheric ozone, and has established frameworks for dealing with climate change, biodiversity, and desertification.
- Global cooperation has dramatically slowed the proliferation of nuclear weapons and encouraged several dozen countries to abandon their quest for such weapons.

These are global achievements of historic proportions. Yet the roots of these successes are almost forgotten today by unilateralist or free-market ideologues in the United States, obscured by a heavy dose of reactionary ideology and rhetoric that claim, against the facts, that such progress was ordained by market forces alone and was not the result of the massive collective actions and financial backing that went into these efforts.

The New York University economist William Easterly played to the Washington right wing in recent years when he waved a red flag against foreign aid, charging that it was $2.3 trillion down the drain in the past fifty years. It is a false charge, but it was eagerly and gratefully received by cynical U.S. politicians who would like to be absolved from spending even 70 cents in budgetary outlays for each $100 of U.S. national income, the agreed on but unfulfilled global target for official development aid, to improve the lot of the world's poor.

The charge is phony in two ways. The first is the claim itself that aid has failed. While that headline claim is eagerly embraced, even Easterly admits the contrary, but his admission is buried in the middle of his book, where he acknowledges that

> Foreign aid likely contributed to some notable successes on a global scale, such as dramatic improvement in health and education indicators in poor countries. Life expectancy in the typical poor country has risen from forty-eight years to sixty-eight years over the past four decades. Forty years ago, 131 out of every 1,000 babies born in poor countries died before reaching their first birthday. Today, 36 out of every 1,000 babies die before their first birthday.

Moreover, Easterly's insinuations about aid failures, exaggerated as they are, are also completely Washington focused. Aid from Japan, for example, which played an important role in building the basic infrastructure and technological capacity that enabled Southeast Asia to attract Japanese private investment and to become industrial exporters in the 1960s and onward, is simply not evident in his account. More generally, as we will note in Chapters 9 and 10, today's successful emerging markets, such as Korea, Taiwan, China, and India, have *all* been the beneficiaries of important external assistance.

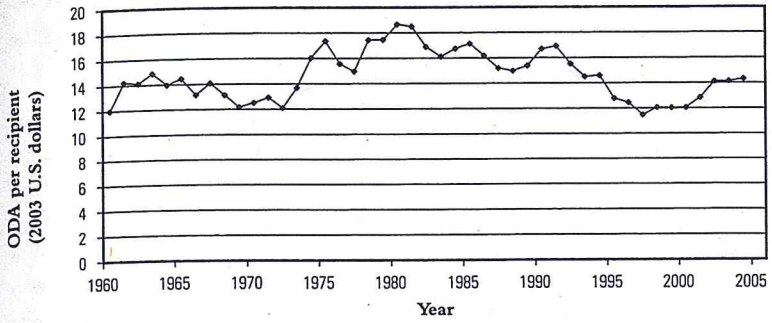
The second fallacy is the implication that $2.3 trillion is so gargantuan as to prove obviously, and without further calculation, that aid has been a mas-

sive waste on a global scale. I dare say that most people before making the calculation would have a hard time knowing whether the sum is actually gargantuan or not. It is not easy to judge, since it signifies *all* aid to *all* countries from *all* donors over a fifty-year period! That's a hard sum to contemplate accurately. A little calculation puts the figure in perspective. There were, on average, three billion people in low-income countries during the fifty years, so averaging the aid by person per year tells us that the average aid recipient received the grand sum of $15 each year (Figure 2.4). Recognizing the enormous worldwide gains in literacy, life expectancy, disease control, reduced poverty, reduced fertility, school attendance, HIV treatments, and so on, one would think that aid outlays of $15 per person per year have surely been among the greatest bargains on the planet. Another way to judge the modest magnitude of aid is to realize that it is currently around 0.3 percent of the income of the donor countries, meaning 30 cents in aid per $100 of income. In the United States, it stands at just 17 cents per $100 of national income, that is, 0.17 percent.

Put $2.3 trillion in comparison with U.S. military spending during the same period, which totaled $17 trillion, nearly eight times the aid levels. And we can note that the Iraq War cost $500 billion in direct outlays by the middle of 2007 and about the same amount in indirect costs (for example, the costs of medical and long-lasting disability care for veterans). The Vietnam War cost at least $500 billion in today's dollars. Suddenly $2.3 trillion over a fifty-year period for the entire world of development—health, water, disease, literacy, family planning, roads, power, courts, democracy, famine, and other emergency relief—is not so self-evidently extravagant.

The truth is that Easterly's heated attacks don't undermine the case for aid, but usefully remind us that aid can be wasted. He and I certainly do agree that much aid has been wasted, especially aid that has gone for U.S. political purposes with little regard for a true developmental impact (for example, aid to support U.S. foreign policies vis-à-vis the Cold War, the Israel-Palestine conflict, and the war on terror), or aid to pay the salaries of high-priced U.S. and European consultants, or expensive shipments of U.S. food to satisfy farm-state senators, when aid to raise Africa's own food production would have provided vastly less expensive and longer-lasting benefits. Indeed, I strongly applaud Easterly's conclusion at the end of his long diatribe against aid, when he finally gets around to his own positive recommendations:

Figure 2.4: Official Development Assistance from All Donors to All Developing Countries, per Person in Developing Countries



Source: Calculated using data from OECD (2007)

> Put the focus back where it belongs: get the poorest people in the world such obvious goods as the vaccines, the antibiotics, the food supplements, the improved seeds, the fertilizer, the roads, the boreholes, the water pipes, the textbooks, and the nurses. This is not making the poor dependent on handouts; it is giving the poorest people the health, nutrition, education, and other inputs that raise the payoff to their own efforts to better their lives. (Just like a National Science Foundation fellowship to get a Ph.D. once increased the payoff to my own efforts to pursue a career.)

This is a good list, and it includes the kinds of investments being supported by the Millennium Village Project described in Chapter 10.

Fortunately, much of the critical groundwork for renewed global cooperation is in place. In each area of concern we are starting from a track record of success, not failure, but we are facing harder problems and in recent years a flagging of wills and memory. Here's a quick rundown of some of the key challenges.

Environment

Progress has been made in many middle-income and rich countries in the control of local pollution and even cross-border pollution across neighbors. Dirty air and water have been controlled in much of the world. Gasoline is now unleaded. Smokestack scrubbers reduce sulfur dioxide. Catalytic con-

verters reduce urban smog. Even the tough challenge of stratospheric ozone depletion has been contained. But the crowded planet and burgeoning populations are leading to environmental devastation in other areas still not controlled: species extinction, global climate change, desertification, and the massive destruction of natural habitats.

Population

Fertility rates have declined below 4 children per woman on average in almost every country outside of tropical Africa (the exceptions in 2005 are Guatemala, 4.3; Lao PDR, 4.5; Maldives, 4.0; Pakistan, 4.1; Solomon Islands, 4.0; the West Bank and Gaza, 4.6; and Yemen, 5.9), but they are still above 4 in thirty-five out of forty-six tropical African countries (with the exceptions mainly in countries with small populations). Population control is arriving late to the most difficult places, the regions with massive illiteracy, lack of health care, high child mortality, and typically, low social conditions for women.

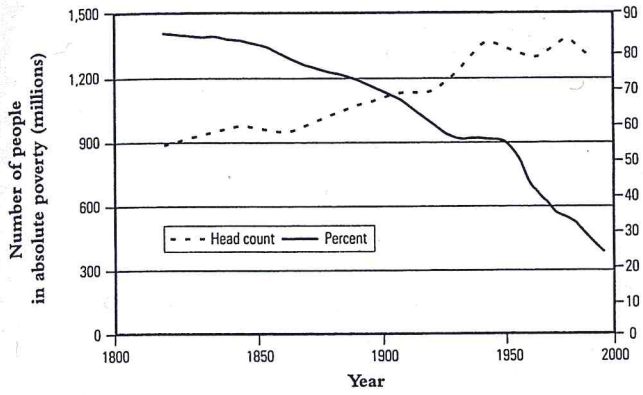
Extreme Poverty, Hunger, and Disease

The world has seen an astounding reduction in extreme poverty since the beginning of the Industrial Revolution. Before 1800, perhaps 85 percent of the world's population lived in what we would consider today to be extreme poverty. By 1950, this had reached the 50 percent mark as shown in Figure 2.5. Since then, extreme poverty has continued to decline to below 25 percent in 1992 and to just 15 percent today. The challenge now is that extreme poverty is concentrated in the toughest places: landlocked, tropical, drought-prone, malaria-ridden, and off the world's main trade routes. It is no accident that today's poorest places have been the last to catch the wave of globalization. They have the most difficulty in getting on the ladder of development.

THE CHALLENGE OF GLOBAL COOPERATION

To solve the remaining dire problems of environmental degradation, population growth, and extreme poverty, we will need to create a new model of twenty-first-century cooperation, one that builds on past successes and overcomes today's widespread pessimism and lack of leadership. This century's global cooperation won't be led by any single country. It will be based on global agreements and international law, first and foremost as contained in the treaties and agreements that constitute the Millennium Promises. Financial contributions and ideas will have to come from many quarters, not only the rich countries but also a host of emerging markets and emerging powers, including Brazil, China, India, South Africa, and Nigeria, among others. Such multipolar cooperation is time-consuming and often contentious. Solutions will be complicated; the problems of sustainable development inevitably cut across several areas of professional expertise, making it hard for any single ministry—or academic department, for that matter—to address the issues adequately. A sound climate change strategy must be informed by climate science, environmental engineering, energy systems, economics, ecology, hydrology, agronomics (plant breeding), infectious disease control, business, and finance. Solutions for African poverty require strategies that simultaneously tackle disease control, agricultural modernization, ecological conservation, fertility control, the upgrading of infrastructure, and a host of other components. Governments will need to be restructured for such twenty-first-century problems.

Figure 2.5: Global Poverty from 1820 to 1992



Source: Bourguignon and Morrisson (2001)

The new global cooperation will also include an increased role for businesses and civil-society organizations. Modern businesses, especially the vast multinational companies, are the repositories of the most advanced technologies on the planet and the most sophisticated management methods for large-scale delivery of goods and services. There are no solutions to the problems of poverty, population, and environment without the active engagement of the private sector, and especially the large multinational companies. Yet the main objective of such companies is to earn profits rather than to meet social needs. The two are definitely not incompatible, but they are not the same. It will take hard work to bring together the leaders of business, government, and nongovernmental organizations to ensure that private-sector incentives and societal needs are harmonized.

The role of the global citizenry will also be crucial in ensuring that governments abide by the commitments they have undertaken in the name of their citizens. The temptation of any individual government to shirk its global obligations is ever present. Global cooperation is sustainable only if such shirking is punished, most important, by a loss of reputation throughout the world. Governments can be shamed into doing the right thing but only if the global citizenry is paying attention, understands the stakes, cares about the outcomes, and has the organizational heft to take on the shirkers. When governments fail to follow through, they need to know that global public opinion will raise the costs of shirking. Many NGOs are now playing that role effectively, monitoring governments for follow-through on promises of aid, environmental management, clean governance, the fight against disease, and commitments in the fight against poverty. The remarkable social networking strategies now being deployed will strengthen this crucial role of global citizenry.

All of this will require financial help from the rich-world governments, at levels that have long been promised but not delivered. The good news is that official development assistance (ODA) as a share of donor-country income is beginning to rise again after a long downslide. The ratio of ODA to donor income reached its nadir in the late 1990s, falling from around 0.5 percent in the early 1960s to roughly 0.35 percent in the 1980s and to a mere 0.22 percent in 1997. This was contrary to the long-standing pledge made in 1970 and reiterated countless times thereafter to achieve 0.7 percent of GNP in official development assistance. In 2002, the donor countries again committed to

make concrete efforts to reach 0.7. In 2005, the European Union (but not the United States) set a timetable to do so by the year 2015. The major donors are on the record promising a doubling of aid to Africa (an extra $25 billion per year) by the year 2010, but as of 2007 have not delivered a sustained increase above the 2004 levels. There is still time to make good on the promises, but the clock is running and millions of lives are lost each year by this neglect.

IPCC	Intergovernmental Panel on Climate Change
MDGs	Millennium Development Goals
MENA	Middle East and North Africa
MVP	Millennium Village Project
N_2O	nitrous oxide
NGO	nongovernmental organization
NRR	net reproduction rate
PAI	Population Action International
ppm	parts per million
PPP	purchasing power parity
PPPs	public private partnerships
R & D	research and development
RD & D	research, development, and demonstration
TFR	total fertility rate
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UNFPA	United Nations Population Fund (formerly UN Fund for Population Activities)
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
WHO	World Health Organization
WTO	World Trade Organization

Notes

Chapter 1: Common Challenges, Common Wealth

4 **social insurance and transfer schemes:** Peter Lindert, *Growing Public: Social Spending and Economic Growth since the Eighteenth Century,* vol. 1 (New York: Cambridge University Press, 2004).

10 **"For peace is a process":** John F. Kennedy, Spring Commencement Address, American University, June 10, 1963. http://www.american.edu/media/speeches/Kennedy.htm.

10 **"And we are all mortal":** Ibid.

11 **"legacy of ashes":** Tim Weiner, *Legacy of Ashes* (New York: Random House, 2007).

13 **"ensuring universal access by 2015":** United Nations, Summary of the International Conference on Population and Development (ICPD) Program of Action. www.unfpa.org/icpd/icpd__poa.htm.

13 **G8, the eight richest large economies:** The G8 countries are: Canada, France, Germany, Italy, Japan, Russia, United Kingdom, and United States.

14 Note: The goals for the new millennium were also reflected in commitments on arms control, particularly the control of chemical weapons and nuclear arms mentioned below; this book, however, will not discuss these commitments in detail. The Chemical Weapons Convention (CWC), signed in 1993 and entered into force in 1997, outlaws the stockpiling, production, and use of chemical weapons. The Nuclear Non-Proliferation Treaty (NPT), first signed in 1968, was extended indefinitely in 1995. A year later, the Comprehensive Test Ban Treaty (CTBT) was opened for signatures. Yet these steps marked the apogee of nuclear arms control. Since the mid-1990s, three states have become nuclear powers, and the treaties themselves are threadbare if not torn asunder entirely. The United States has signed the CTBT treaty but not ratified it, while India and Pakistan have not even signed. The chance to restrain the nuclear arms race could easily disappear altogether if the NPT and CTBT are not reinforced by the political and operational support of the major powers.

15 **"reflexive practice":** Donald Schön, *The Reflective Practitioner: How Professionals Think in Action* (New York: Basic Books, 1983).

15 **new methods of training:** I am pleased to cochair the Commission on the Education of International Development Practitioners, a MacArthur Foundation initiative that is recommending a new approach to professional training in sustainable development. The commission believes that effective professional training in sustainable development should include a focus on cross-disciplinary knowledge; a combination of classroom learning and fieldwork; and skill development that includes the policy sciences, the Earth's physical systems, and management expertise.

Chapter 2: Our Crowded Planet

17 **$60 trillion of output each year:** Unless otherwise noted, I report measured national and global incomes in purchasing-power-parity (PPP) prices. This approach measures each country's na-

tional income not at the prices that prevail in that country but at common prices that are roughly benchmarked to those that prevail in the United States. Let me use an example to illustrate. Suppose there are two countries, a developing country and the United States. Each country produces haircuts and television sets. We want to compare the average income per person in the two countries. In both countries, the television sets sell for $200 each, while the haircuts are $1 in the poor country and $10 in the United States. The poor country produces 100 haircuts and 10 television sets per person per year, while the United States produces 1,000 haircuts and 100 television sets per person per year. If we use the country's own prices, the average income per person in the poor country is $2,100 (equal to [$1 × 100] × [$200 × 10]), while the U.S. average income is $30,000 (equal to [$10 × 100] + [$200 × 100]). The United States looks nearly fifteeen times richer than the poor country. In fact the "real" difference in income is only ten times, since each commodity is produced in ten times the amount per person in the United States. The developing country looks somewhat poorer than it really is, because individuals in the poor countries will earn less income but also pay less for each haircut. If we use a common set of prices to calculate the income of both countries (specifically, $10 for haircuts and $200 for television sets), the PPP-adjusted income of the developing country is now $3,000 (equal to $10 × 100 + $200 × 10) and the PPP-adjusted income of the United States is $30,000. On a PPP basis, the U.S. income is ten times that of the poor country's. The PPP-adjusted incomes provide a more accurate comparison because they offset the difference of prices of products in the two countries and keep the focus on the differences in physical outputs.

19 **gross world product:** Angus Maddison estimates that GWP rose from $5.3 trillion in 1950 to $33.7 trillion in 1998, calculated in constant 1990 U.S. dollars using purchasing-power-parity-adjusted prices. The World Bank estimates that GWP rose from $41.6 trillion in 1998 to $54.5 trillion in 2005, expressed in constant 2000 PPP-adjusted U.S. dollars. Linking these two estimates gives an 8.2-fold increase of world production between 1950 and 2005 (= 33.7/5.3 × 54.5/41.6).

20 **U.S. per capita income level:** See Robert J. Barro and Xavier Sala-i-Martin, *Economic Growth*, 2nd edition (Cambridge, Mass.: MIT Press, 2004) for a detailed discussion on convergence. There is, of course, statistical uncertainty about the "typical" rate of convergence. In the calculations in the text, I assume that a country that is at half of the income of the technological leader (assumed to be the United States) can achieve convergent growth at a rate 1.5 percentage points per year faster than the growth rate of the leader. In the statistical estimates reported by Barro and Sala-i-Martin, and in similar estimates by other researchers, the range is generally between 1 and 2 percentage points per year faster growth in the follower country (at half of the leader's income).

25 **56 percent of the world economy:** Angus Maddison, *The World Economy: A Millennial Perspective* (Paris: Development Centre of the Organization for Economic Cooperation and Development, 2001).

26 **Cities arose with:** Archeologists and anthropologists have generally assumed that urban settlements arose only with cultivation. It is possible, though, that the first cities (of course with very small populations) arose in regions of intensive hunting and gathering rather than cultivation per se. In any case, the oldest cities arose roughly ten thousand years before the present.

26 **almost all regions of the world:** See Paul Bairoch, *Cities and Economic Development: From the Dawn of History to the Present*, translated by Christopher Braider (Chicago: University of Chicago Press, 1988).

28 **global epidemic of:** For further reading see the September 2007 special issue of *Scientific American*, for a series of important articles on the new epidemic.

29 **It is useful to decompose:** The I-PAT equation is generally attributed to a series of articles and debates in the early 1970s between Barry Commoner on the one side and coauthors Paul Ehrlich and John Holdren on the other. The history of the equation is surveyed by Marion Chartow in "The IPAT Equation and Its Variants," *Journal of Industrial Ecology* 4., no. 4 (2001): 13–29. According to Chartow, the first appearance of equation in its I-PAT form is in P. Ehrlich and J. Holdren, "One-Dimensional Ecology," *Bulletin of the Atomic Scientists*, June 1972, pp. 16–27.

34 **innovations systems:** My colleague Richard Nelson has been the world's leading scholar on mapping the structure and performance of these innovation systems in many parts of the world. For further reading see: Richard Nelson, ed., *National Innovation Systems: A Comparative Analysis* (New York: Oxford University Press, 1993).

38 **"tragedy of the commons":** Garrett Hardin, "The Tragedy of the Commons," *Science* 162 (1968): 1243–48.

38 **variety of quota systems:** J. R. Beddington et al., "Current Problems in the Management of Fisheries," *Science* 316 (June 22, 2007): 1713–16.

39 **Community-based management:** See Elinor Ostrom, *Governing the Commons: The Economics of Institutions for Collective Action* (Cambridge: Cambridge University Press, 1990) and Partha Dasgupta, "Common Property Resources: Economic Analytics," in N. S. Jodha et al., eds., *Promise, Trust, and Evolution* (New Delhi: Oxford University Press, 2007).

39 **restoration of degraded pasturelands:** Dennis Normile, "Getting at the Root of Killer Dust Storms," *Science* 317 (July 20, 2007): 314–16.

40 **megafishes project:** Richard Stone, "Aquatic Ecology: The Last of the Leviathans," *Science* 316 (June 22, 2007): 1684–88.

44 **"The global fossil":** H. H. Rogner, "An Assessment of the World Hydrocarbon Resources," *Annual Review of Energy and the Environment*, 1997.

44 **"global energy demand":** A ton of oil equivalent means an amount of a nonoil energy source, such as coal or natural gas, with the energy content equal to one ton of oil.

44 **current commercial energy use:** Total solar radiation is 174 petawatts, or 174 million gigawatts, compared with average power consumption of 15,000 gigawatts (2004), roughly 10,000 times less than solar radiation. A watt is a measure of energy use per second (specifically, joules per second), so the energy consumption in a period of time is equal to the watts multiplied by the time period. A common unit of energy consumption is kilowatt hours (1,000 watts for one hour of energy consumption).

44 **With improved technologies:** Interestingly, geothermal energy, the heat energy of the Earth's crust resulting mainly from radioactive decay in the Earth's interior, is also in vast supply, orders of magnitude larger than humanity's total commercial energy use. As with solar power, it is currently too expensive to tap commercially in most places, the exceptions being mainly in areas of active seismic activity where tectonic plates meet and thereby allow for large flows of heat from the Earth's interior to the surface. Advances in technology could enable a huge expansion in low-cost access to this vast store of heat energy. One system, known as enhanced geothermal energy, envisions drilling two very deep wells side by side down to a depth of ten kilometers (six miles) or more. At the base of these deep wells, the rock is fractured to create a connection between them. Water is pumped down one of the wells, and steam is generated by the heated water in the other well. The steam is then used to turn the turbines in a power plant. See MIT Inter-Disciplinary Panel on Geothermal Energy, *The Future of Geothermal Energy* (Cambridge, Mass.: MIT Press, 2007). Nuclear power offers another vast potential, though one that is made exceedingly, perhaps unsolvably, complicated by its intertwined links with nuclear weapons. As is well known, there are two potential forms of long-lasting nuclear energy, fission based (utilizing the energy released by splitting uranium and other radioactive materials) and fusion based (utilizing the energy released by the fusion of two hydrogen atoms into a helium atom, as happens in the sun). Only fission exists in commercial form. Fusion power is likely decades away from commercial exploitation but could be a vast source of energy in the twenty-second century and beyond. Uranium-based nuclear energy is a tried-and-true, if highly controversial, technology. It already powers roughly one sixth of the world's electricity production, including one fifth of U.S. electricity production, and around 80 percent of France's electricity. The long-term potential is vast, alongside other energy sources. The public acceptance is highly qualified, however, out of deep fears of leakages of radiation, as in the Chernobyl catastrophe; the difficulties of disposing of nuclear waste products; and the ability to convert and divert nuclear plant materials (both inputs and waste products) into weapons-grade nuclear materials. The expanded use of nuclear power is all but inevitable, notably in China, India, Japan, and several other countries. The biggest fear is that the expansion of nuclear power in some countries, especially the crisis-riven Middle East, can be a pretext for the development of a nuclear weapons industry as well. See MIT Inter-Disciplinary Panel on Nuclear Power, *The Future of Nuclear Power* (Cambridge, Mass.: MIT Press, 2003).

46 **only deepened the insecurity:** Michael Klare, *Blood and Oil: The Dangers and Consequences of America's Growing Dependency on Imported Petroleum* (New York: Metropolitan Books, 2004), and Dilip Hiro, *Blood of the Earth: The Battle for the World's Vanishing Oil Resources* (New York: Nation Books, 2006).

46 **quest for such weapons:** This book does not go into depth on global cooperation regarding weapons of mass destruction, but I mention here the success of the Nuclear Non-Proliferation Treaty (and related treaties on chemical weapons and nuclear testing) to emphasize that the pessimism regarding global cooperation is misplaced not only regarding sustainable development but also regarding the challenges of global security. While the Nuclear Non-Proliferation Treaty has not ended proliferation, it has dramatically slowed proliferation and caused dozens of countries to abandon nuclear programs. See Joseph Cirincione, *Bomb Scare: The History, Theory and Future of Nuclear Weapons* (New York: Columbia University Press, 2007). In recent years, however, the treaties have come under increasing strain partly because the United States and other nuclear powers have failed to take concrete steps toward eventual nuclear disarmament, as required by the treaty.

47 **the agreed on but unfulfilled:** Since 1970 the world community has agreed that the rich-country governments should devote 70 cents for every $100 of national income toward development aid. This 0.7 percent standard has been repeatedly reaffirmed, for example, in 2002 at the Financing for Development Summit in Monterrey, Mexico, where the world's governments, including that of the United States, pledged to "make concrete efforts toward the target of 0.7 percent of gross national product as official development assistance."

47 **"Foreign aid likely":** William Easterly, *The White Man's Burden* (New York: Penguin, 2006), p. 176.

49 **"Put the focus back":** Easterly, *The White Man's Burden,* pp. 368–69.

50 **tropical Africa:** Tropical Africa excludes South Africa; Lesotho; Namibia; and the five countries of North Africa: Algeria, Egypt, Libya, Morocco, and Tunisia.

50 **exceptions mainly in:** Botswana, 3.0; Cape Verde, 3.5; Comoros, 3.8; Gabon, 3.7; Lesotho, 3.4; Mauritius, 2.0; Namibia, 3.7; São Tomé and Principe, 3.8; Swaziland, 3.9; Seychelles, 2.1; Zimbabwe, 3.3.

50 **to just 15 percent today:** Shaohua Chen and Martin Ravallion, "How Have the World's Poor Fared since 1980?" *The World Bank Research Observer* 19, no. 2 (fall 2004): 152.

53 **There is still time:** All data in this paragraph refer to the twenty-two country members of the Development Assistance Committee (DAC) of the Organization of Economic Cooperation and Development (OECD).

Chapter 3: The Anthropocene

58 **hunter-gatherers might have totaled:** J. L. Chapman and M. J. Reiss, *Ecology* (New York and Cambridge: Cambridge University Press, 1998).

59 **hunted the large animals to extinction:** P. S. Martin and H. E. Wright, eds., *Pleistocene Extinctions: The Search for a Cause* (New Haven, Conn.: Yale University Press, 1967).

65 **Sir William Crookes, predicted:** In Crookes's presidential address to the British Association in Bristol in 1898.

66 **Figure 3.2(b):** This graph, carefully constructed by economic historian Angus Maddison, attempts to measure the level of economic production per person across many centuries and very different regions of the world. While it is a bit heroic to make such a graph, considering the difficulties of comparing the economies of the preindustrial age with those of today, there is clear evidence of its core finding of an unprecedented takeoff of economic productivity around 1800.

67 **The Nobel laureate chemist:** Paul J. Crutzen, and Eugene F. Stoermer, "The 'Anthropocene,' " *International Geosphere-Biosphere Programme Newletter* 41 (May 2000): 17–18.

68 ***50 percent of the Earth's photosynthetic . . .*:** Peter M. Vitousek, et al. "Human Domination of Earth's Ecosystems," *Science* 277, no. 5325, (July 25, 1997): 494–99.

72 **" fully exploited, overexploited, or depleted,":** Commission on Geosciences, Environment and Resources (CGER), *Sustaining Marine Fisheries,* Ocean Studies Board, 1999.

74 **A recent study of degradation:** H. K. Lotze et al., "Depletion, Degradation, and Recovery Potential of Estuaries and Coastal Seas," *Science* 312 (June 23, 2006): 1806–9.

74 **"Reconstructed time lines":** Ibid., p. 1806.

75 **"Our results indicate":** Ibid., p. 1808.

75 **"Although 22% of":** Ibid.

75 **But, alas, some degradation:** Ibid., p. 1806.

75 **China is currently:** MIT Inter-Disciplinary Panel on Coal, *The Future of Coal: Options for a Carbon-Constrained World* (Cambridge, Mass.: MIT Press, 2007).

76 **China's annual production is now soaring:** India's automobile sales are also rising strongly at about 15 percent per year, though at a much lower rate than in China. In 2006 sales were around 1.3 million, and are expected to rise to 2.1 million vehicles by 2010 (see *Financial Times,* September 4, 2007).

78 **could well be human forcings:** James Hansen et al., "Climate Change and Trace Gases," *Philosophical Transactions of the Royal Society A* 365 (May 2007): 1925–54.

78 **A slight rise:** James Hansen, "Climate Catastrophe," *New Scientist,* July 28, 2007.

79 **has been studied extensively by my colleague Wallace Broecker:** See Richard Alley, "Wally Was Right: Predictive Ability of the North Atlantic 'Conveyor Belt' Hypothesis for Abrupt Climate Change," *Annual Review of Earth and Planetary Sciences* 36 (2007): 241–72, for recent authoritative support for Broecker's hypothesis.

79 **a sudden abrupt cooling:** These and other abrupt-change findings and scenarios are ably described in Fred Pearce, *With Speed and Violence* (Boston: Beacon Press, 2007).

81 **"Thus, human societies":** Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed* (New York: Viking, 2004), p. 38.

Chapter 4: Global Solutions for Climate Change

87 **Figure 4.2:** Figure based on P. Brohan, J. J. Kennedy, I. Harris, et al., "Uncertainty Estimates in Regional and Global Observed Temperature Changes: A New Dataset from 1850," *Journal of Geophysical Research* 111 (2006).

87 ***Stern Review on Climate Change*:** Nicholas Stern, "The Economics of Climate Change," *The Stern Review* (Cambridge: Cambridge University Press, 2007).

87 ***"Intergovernmental Panel on Climate Change":*** Intergovernmental Panel on Climate Change Fourth Round Assessment. Information available at: http://www.mnp.nl/ipcc/.

88 **Polar bears and alpine species:** Steven C. Amstrup, Bruce G. Marcot, and David C. Douglas, *Forecasting the Range-wide Status of Polar Bears at Selected Times in the 21st Century* (Virginia: U.S. Geological Survey Administrative Report, 2007).

88 **higher-latitude environments:** Carbon fertilization is the hypothesis, somewhat debated, that higher atmospheric CO_2 concentrations may "fertilize" crops and raise the productivity of photosynthesis. There are many countervailing arguments as well, so the generality of carbon fertilization as a likely effect is uncertain.

88 **interact with increased:** Recent research suggests that air pollution in Asia, caused by the burning of biomass and fossil fuels, has created a massive atmospheric brown cloud (ABM) over India. The ABM tends to create drying conditions that lower crop productivity in India. The combination of greenhouse gas emissions and the ABM have had a large adverse effect on crop yields. See Maximillian Auffhammer et al., "Integrated Model Shows That Atmospheric Brown Clouds and Greenhouse Gases Have Reduced Rice Harvests in India," *PNAS* 103, no. 52 (December 26, 2006).

91 **greenhouse gases can be reversed:** Technically, greenhouse gases are compared according to their radiative forcing, that is, how much they are warming the Earth as a result of their greenhouse effect. The radiative forcing is a result of two measures. The first is the efficiency of the greenhouse effect of the particular gas, that is, how much greenhouse effect results from a given increase in ppm of the molecule. The second is the actual increase in atmospheric concentration of the gas. The increase itself results from the balance of two forces: the emissions of the gas into the atmosphere and the natural removal of the gas from the atmosphere, for example,