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Common Wealth

ECONOMICS FOR A CROWDED PLANET

Jeffrey D. Sachs

PENGUIN BOOKS

Chapter 2

Our Crowded Planet

We have reached the beginning of the twenty-first century with a very crowded planet: 6.6 billion people living in an interconnected global economy producing an astounding $60 trillion of output each year. Human beings fill every ecological niche on the planet, from the icy tundras to the tropical rain forests to the deserts. In some locations, societies have outstripped the carrying capacity of the land, at least with the technologies they deploy, resulting in chronic hunger, environmental degradation, and a large-scale exodus of desperate populations. We are, in short, in one another's faces as never before, crowded into an interconnected society of global trade, migration and ideas, but also risks of pandemic diseases, terror, refugee movements, and conflict.

The world is in fact experiencing several simultaneous transformations that offer the prospect of shared prosperity or devastating crises depending on how we respond as a global society. Here are six Earth-changing trends, unprecedented in human history.

First, the process of sustained economic growth has now reached most of the world, so that humanity on average is rapidly getting richer in terms of income per person. Moreover, the gap in average income per person between the rich world, centered in the North Atlantic (Europe and the United States), and much of the developing world is narrowing fast.

Second, the world's population will continue to rise, thereby amplifying the overall growth of the global economy. Not only are we each producing more output on average, but there will be many more of us by midcentury. The scale of the world's economic production is therefore likely to be several times that of today.

Third, the rise in income will be greatest in Asia, home to more than half of the world's population. As a result, the world will not only be much richer by 2050 but will have its economic center of gravity in Asia.

Fourth, the way people live is changing fundamentally as well, from rural roots that stretch back to the beginning of humanity to a global urban civilization. We crossed the midway point between urban and rural in 2008, on a one-way path to an urban-based society.

Fifth, the overall impact of human activity on the physical environment is producing multiple environmental crises as never before in history. The environmental crises we face cannot be compared with the past because never before in history has the magnitude of human economic activity been large enough to change fundamental natural processes on the global scale, including the climate itself.

Sixth, the gap between the richest and the poorest is widening to proportions simply unimaginable for most people. This is not contradictory to the idea that on average the poor are getting richer. Most are, but the bottom billion people on the planet are stuck in a poverty trap, which has prevented them from experiencing sustained economic growth. The center of the crisis is in sub-Saharan Africa. This is also the site of the fastest population growth, meaning that the population bulge is occurring in the part of the world that at this point is least able to generate jobs.

This chapter discusses these six aspects of our crowded planet, with a view to global problem solving. The first part of the chapter lays out the six trends. The second part of the chapter discusses the strategy of sustainable development. The final part of the chapter discusses the challenge of global cooperation, because any viable strategy to achieve sustainable development must be a global strategy, with shared participation among the world's countries.

SIX TRENDS THAT WILL SHAPE THIS CENTURY

The Age of Convergence

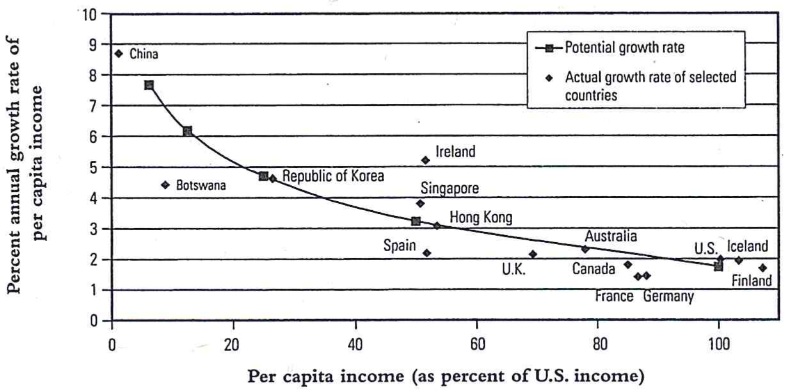
The planet has filled up with people and economic activity much faster than we have realized. The world's population has risen by more than 4 billion people since 1950, from 2.5 billion to 6.6 billion today. Sub-Saharan Africa's population has more than quadrupled, from 180 million to around 820 million. So too has the population of western Asia, which includes the Middle East, Turkey, and the Caucasus region, from 51 million in 1950 to around 220 million in 2007. And the global economy, which provides a rough indication of human pressures on the Earth's environment, has of course soared even faster, because population growth has been accompanied by a steep rise in income per person. A rough estimate suggests that the gross world product, the sum of the gross domestic products of every nation in the world, has risen by a remarkable eight times since 1950.

A crucial economic point is that there is a lot more economic growth to come, not only because the global population will continue to rise, but more important, because income per person will continue to rise, especially in today's poorer countries. The good news is that most of the world, including large parts that remain poor today, has unlocked the mysteries of sustained economic growth. What was once the formula of success of a small part of the world—Europe, the United States, Japan, and a handful of other places—is now the prize of Brazil, China, India, and other vast populations. Rapid economic growth and the spread of prosperity are on the way. This spread of prosperity is fueled by globalization—the networks of trade, finance, production, technology, and migration—which creates deep interlinkages across the world, and which helps to spread the technologies that underpin productivity and economic development.

Economists use the concept of convergence to describe the processes by which the poorer countries catch up with the richer countries. Convergence occurs when the per capita income in poorer regions rises more rapidly in percentage terms than the per capita income of the richer regions, so that the ratio of per capita incomes of the poorer regions to the richer regions rises toward one, that is, toward the same standard of living. As Brazil, China, and India achieve market-based economic growth based on globalization, they are able not only to raise living standards but to narrow the per capita income gap with the rich countries. Through their competitive exports, these countries earn the foreign exchange to purchase state-of-the-art technologies, for example, in communications and information technology. The rapid uptake of technology leads to a similarly rapid growth of national income, and also improves the competitiveness of the economy in world markets. A virtuous circle of rapid economic growth is created, based on rapid technological upgrading paid for through the rapid growth of exports. This is a wonderful process, making available to billions of people the wonders of modern science and technology. Most of the world is now part of this convergence club, as economists call the countries that have successfully integrated into global markets, and thereby achieve economic growth at a convergent rate (that is, economic growth that is faster than that in the rich countries).

How fast is future economic convergence likely to be? A useful rule of thumb is the following: the poorer the country, the faster its economic growth in comparison with the leader, as long as the preconditions for convergence are met (that is, as long as countries are not stuck in the poverty trap). Today's technological leader, the United States, sustains average annual growth in per capita income of around 1.7 percent, with a per capita income level of around $40,000 per year. The growth of a "follower," or lagging country, depends on the gap in income with the United States. At $20,000, or half of the U.S. per capita income level, growth will exceed the U.S. rate by around 1.5 percentage points per year, so that growth will be around 3.2 percent per year (= 1.7 + 1.5). At $10,000, or a quarter of U.S. per capita income, another 1.5 percentage points per year can be added, so that growth will be around 4.7 percent per year (= 1.7 + 1.5 + 1.5). The overall pattern is shown in Figure 2.1. The horizontal axis shows the income level of the laggard country as a proportion of U.S. per capita income as of 1990. The vertical axis measures the growth rate, and the solid curve shows the growth rate expected on the basis of convergence. The poorer the country, the faster is the growth that it will tend to achieve.

Figure 2.1: Annual Growth Rates from 1990 to 2005 vs. Income Level in 1990



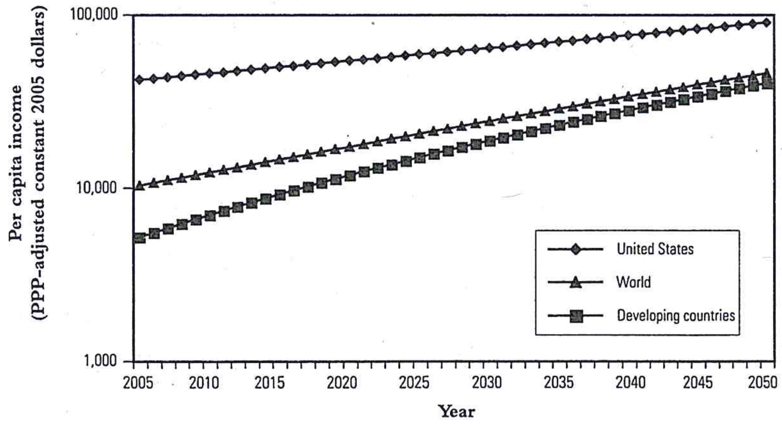
Source: Calculated using data from World Bank (2007)

The figure also adds some dark points for per capita growth during 1990–2005 for a selection of fast-growing countries in each income range. We see a group of poor countries with exceptional growth, a group of middle-income countries with rapid growth somewhat less than the growth of the poor countries, and a cluster of rich countries with modest yet positive growth. These fast growers in each income class illustrate how convergence is achieved when other obstacles (especially due to geography, infrastructure, and politics) are overcome. Most poor countries fall far short of their potential for convergence because of notable liabilities regarding their baseline levels of infrastructure, health, education, or governance. Some of the poorest countries don't grow at all because they are stuck in a poverty trap.

More and more countries are joining the convergence club. Literacy has spread to almost all of the world's populations. Electrification and roads have come to the villages of India and China and dozens of other low-income countries. Information technology, starting with the ubiquitous cell phone, and now extending to wireless Internet, is reaching the most remote areas of the world. National aspirations to join the global economy are nearly universal. Sovereignty is the rule rather than the exception in vast regions of the world that until two generations back were under colonial rule. There is, in short, no reason why nearly all of the world will not be part of the convergence club in the first part of the twenty-first century. This would imply the acceleration of total world growth in the coming years, and such a trend is evident in the past half century.

It is instructive to apply the convergence framework to the future development of per capita income in different parts of the world. Suppose that all parts of the world join the convergence club, and thereby have the chance to narrow their income level gaps with the high-income countries. Let's then run the clock forward to 2050, assuming that U.S. economic growth remains at its historical average (1.7 percent per annum) while the rest of the world achieves economic growth in proportion to the income gap with the United States. The poorest countries grow most rapidly, and then slow toward 1.7 percent per annum as they close the income gap with the United States. As a result of these assumptions, global income per person is projected to follow the path shown

Figure 2.2(a): The Convergence of Global Income per Capita through 2050



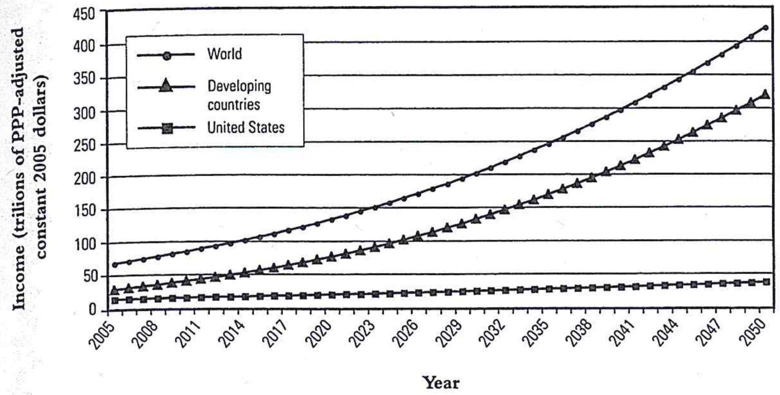
Source: Calculated using data from World Bank (2007)
Note: Vertical axis on logarithmic scale. Income is measured in purchasing power parity (PPP) to adjust for difference in price levels across countries.

in Figure 2.2(a), where we show the world average, the U.S. curve, and the path for today's developing countries. World per capita income grows by 4.5 times between 2005 and 2050 in this simple model. By 2050, today's developing countries would have an average income of $40,000 per person, roughly equal to U.S. income in 2005, and the United States would have a projected 2050 level of $90,000. Of course, this scenario is highly optimistic in that it assumes the world avoids any prolonged crisis, that the United States grows at the historical average, and that all other countries achieve convergent growth.

More People and Higher Incomes

Not only will most of the world be richer, but there will be a lot more people around enjoying those higher incomes. The world's population continues to grow rapidly, even though the proportional rate of population growth (each year's increase relative to the size of the global population) has declined. The United Nations Population Division makes several forecasts of the world's population based on different assumptions about the average number of births per woman (the fertility rate). The medium forecast, deemed to be the most likely, envisions that the global population will rise from 6.6 billion in 2007 to

Figure 2.2(b): World Product through 2050



Source: Calculated using data from World Bank (2007)

9.2 billion in 2050. This is not as large as the population increase over the past half century, but it is still a whopping 2.6 billion people to be added to an already crowded planet. Indeed, I will argue at some length that this is too many people to absorb safely, especially since most of the population increase is going to occur in today's poorest countries. We should be aiming, as we've noted earlier, to stabilize the world's population at 8 billion by midcentury.

The total magnitude of economic activity on the planet is calculated by multiplying the average income per person by the number of people. In our convergence scenario the world's average income per person rises by around fourfold between 2005 and 2050. In the medium-fertility forecast of the UN, the world's population rises by around 40 percent, or a factor of 1.4 times. Therefore, the gross world product rises, in this scenario, by 6.3 times, from around $67 trillion in 2005 to around $420 trillion in 2050, as shown in Figure 2.2(b). With a 2050 population at 8 billion rather than 9.2 billion, and the same per capita income, the global world product would reach around $365 trillion rather than $420 trillion. Either way, there is a lot of pent-up economic growth in the world today, which will result from technological catch-up.

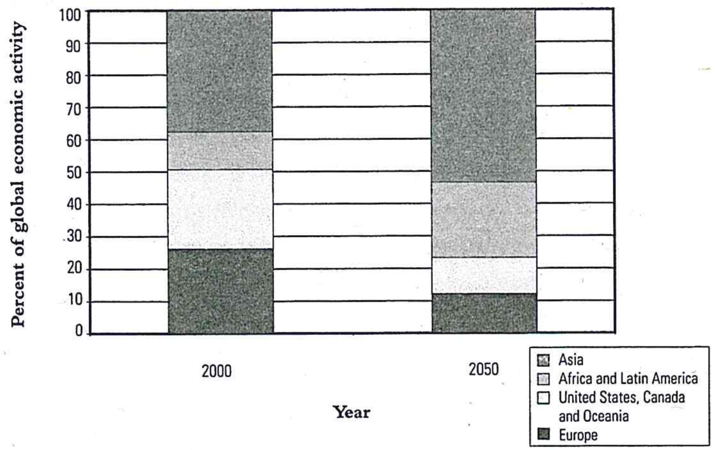
Let me emphasize, once again, that these scenarios are highly optimistic but convey the underlying power of convergence, the dominant force at play in the world economy in our era. The overall lesson is that the world economy will be bigger, much bigger, by 2050, even if we can't say precisely by how much. That economic growth can be monumentally good for human well-being if we can manage the side effects, especially vis-à-vis the environment.

The Asian Century

Rapid catch-up growth in Asia will bring about a historic shift in the center of gravity of the world economy. Since 1800, the North Atlantic economies have been the world's dominant economies and political powers. The cataclysms of World War I, the Great Depression, and World War II did not shake the dominance of the North Atlantic economies, though they did shift the balance of geopolitical influence away from Europe, especially the British Empire, to the United States. Now, after many centuries, the unquestioned economic and geopolitical dominance of the North Atlantic will end. The American century will end sometime in the second quarter of the twenty-first century, when Asia becomes the center of gravity of the world economy, in the sense of producing more than half of the world's income (Figure 2.3). The end of the American century will *not* be the result of any collapse of America's well-being but rather the rise of Asia's economic power.

In the long haul it is natural that Asia should be the center of gravity of the world economy, since it is the center of gravity of the global population. In 1820, Asia constituted perhaps 56 percent of the world economy. With the onset of industrialization in Europe and North America, Asia's share declined to 28 percent by 1900. With Asia's turmoil between 1900 and 1970, the share declined further, to reach a low point of around 18 percent of the world's output in 1950. Then began the great convergence. Asia's share of world income recovered to around 23 percent in 1970 and to 38 percent by 2000. According to the convergence scenario, Asia's share of global income would rise to around 49 percent by 2025 and to around 54 percent by 2050.

Figure 2.3: Economic Activity by Region in 2000 and 2050 (projected)



Source: Calculated using data from Maddison (2001)

History has shown that profound geopolitical frictions, even bloodshed, can accompany the changing fortunes of leading powers. The rise of Germany and Japan in the early twentieth century gave rise to lethal rivalries and armaments races with the leading powers, Great Britain and the United States. Geopolitical jealousies flared. Militarists and demagogues in Germany and Japan argued that their place in the sun was being blocked by the United Kingdom and the United States, and that war was the only solution. And in the leading countries, politicians often took provocative steps—for example, the harsh terms after World War I against Germany—which ended up fanning the flames.

In our day, America's continued assertions of preeminence in global power could cause dangerous frictions with China, India, and other rising regional powers. And if America's assertions of power are again carried to unrealistic extremes, as in the unprovoked war in Iraq, the regional and global reactions are likely to be swift and severe. The belief among U.S. neoconservatives that the United States is the world's sole superpower and can therefore have its way is passé and will become even less true in the coming decades. Such unrealistic views would no doubt trigger similarly unrealistic nationalism within China and India. Power is already diffusing widely in the twenty-first century. A new kind of global politics must take shape, built not on U.S. or Chinese preeminence, but on global cooperation across regions. Despite the reveries and fantasies of some, the age of empire is over, and certainly the age of a U.S. empire. We are now in the age of convergence.

The Urban Century

The economic shift from the North Atlantic to the Pacific and Indian oceans is not the only fundamental change ahead. For the first time in human history, most of the world's population will live in urban centers rather than villages. From the origin of the species through the birth of agriculture and right up to 2007, most of the world's people have been residents of rural communities rather than towns and cities. In prehistory the world was, of course, entirely rural. Cities arose with the end of the last ice age and the rise of agriculture some ten thousand years ago. The essence of city life is a nonagricultural community that obtains most of its food by trading with the countryside, or that extracts food from the countryside in a coercive manner (taxation, slaveholding, tribute, or the like). When agricultural productivity is low—so that the typical farm family basically feeds itself, with only a small surplus to trade with urban dwellers—most of the population must be engaged in food production in order to subsist. It is only when agricultural productivity is very high—so that a farm family can feed many urban residents—that a significant share of the population can reside in urban areas and be engaged in manufacturing and services. (Some manufacturing and services can take place in rural areas as well, but in general, such activities benefit from the density of urban life. Thus, rurality is largely but not entirely synonymous with agriculture, and urbanism is largely but not entirely synonymous with manufacturing and services.) Thus, until the rise of agricultural productivity in the eighteenth century in the North Atlantic (England, Holland, Flanders), almost all regions of the world at all times were 90 percent or more rural, with a mere sliver of the population living in the cities.

The rise of scientific farming—including modern seed varieties, chemical fertilizers, modern irrigation, mechanization, and innovations in farm management (crop rotations, tillage, pest control, and more)—has enabled a declining share of the world's population to feed all the rest and, therefore, has enabled a rising share of the world to live in cities. From less than 10 percent in 1800, the urban share rose to around 13 percent in 1900, 29 percent in 1950, 47 percent in 2000, and 50 percent in 2007. High-productivity farming has gone hand-in-hand with overall economic development, so the high-income world has also been the first to urbanize, reaching 50 percent urban by around 1950 and 75 percent urban today. The low-income world will reach 50 percent urban only around 2017, compared with around 44 percent today. Yet urbanization has risen steadily in virtually all parts of the world as crop production per hectare and, more important, crop production per farm family have continued to rise over time. In the United States, with its enormous output per farmer (due both to high productivity per land area and large area per farm),

farm families constitute just 1 percent of the population and are able to feed the other 99 percent.

In 2008, the historic, and presumably irreversible, halfway mark was reached when half the world was urban and half rural. By 2030, based on current (and admittedly uncertain) trends, the world might be 60 percent urban and just 40 percent rural. Indeed, the UN projects that *all* of the 1.7 billion population increase between now and 2030 (in the medium-fertility forecast) will take place not only in the developing world but in the *cities* of the developing world.

The rising rates of urbanization can have countless benefits for the world, including the low-income countries. From the earliest days of civilization, cities have been the site of technological advancement, science, and productivity advancement due to specialization and the division of labor. Thus, agricultural productivity not only frees labor to work in cities but helps to unleash the technological advances that are part and parcel of urban life. The high population densities of urban settlements have other benefits as well, including much lower costs per person than in rural areas of providing roads, power, clinics, and schools to the population.

Yet urban life raises its own host of challenges, many of them of profound significance for sustainable development. In the worst cases, rural populations migrate into urban areas not because of rising farm productivity or the lure of urban jobs but out of desperation and hunger in the countryside. Urban slums then complement rural desperation. Hunger itself is urbanized, and young, unemployed men on the prowl may create urban settings of violence and insecurity. A rural crisis can thereby become an urban nightmare.

Even if such crises are avoided by adequate urban job creation, rising farm productivity, and slowing population growth rates in rural areas, urbanization can pose many additional challenges. The enormous densities of urban populations mean that pollutants, too, are heavily concentrated, far above the power of nature to disperse the pollutants through harmless flows into waterways and the atmosphere. Therefore, unless pollution is controlled through appropriate technologies and policies, cities can become sites of untold ecological destruction. Also, by bringing millions of people into proximity, cities have long been host to infectious diseases that depend on large populations of susceptible individuals to sustain the long-term transmission of the disease. Moreover, the rising populations of large cities will be vulnerable to other natural hazards, including floods, landslides, and earthquakes. This is especially the case because the world's cities have been heavily concentrated along the coastlines to take advantage of access to global trade, fisheries, and the amenities of coastal life. My colleagues at The Earth Institute have calculated that roughly 10 percent of the world's population lives in low-lying coastal zones (within one hundred kilometers of the coast and at less than ten meters above sea level), though such areas constitute a mere 2.2 percent of the Earth's land area. This implies, of course, that such low-lying coastal settlements are roughly five times more densely populated than the average land area on the planet. Of the people living in low-lying coastal zones, about 60 percent are in coastal cities. As the Earth's climate changes in future decades, rising sea levels and increasingly intense tropical storms will threaten these coastal settlements around the world. The New Orleans tragedy of Hurricane Katrina could be replayed many times.

And if these worries are not enough, we are discovering that the modern style of urban (and suburban) living has itself become an unanticipated health hazard. Today's urban citizens tend to walk less, eat more, and eat more unhealthy foods than ever before. With blinding speed, still not recognized in most of the world, populations are moving rapidly from one kind of malnutrition—a shortfall of calories, proteins, and micronutrients—to another kind of malnutrition—an excess of calories, harmful fats (especially industrially synthesized transfats), and sedentary lifestyles shaped by the automobile and the television set. The result is a global epidemic of obesity, cardiovascular disease, and adult-onset diabetes, the devastating lifestyle disease of the modern urban age. We shouldn't be entirely shocked. Each new scale of human settlement, from forager group to village to city, has entailed new diseases, though in the past they were infectious diseases. As in the past, we will learn to adjust to the new dangers, but a time lag could impose unnecessary suffering.

All this means that the science of urban ecology—linking human activity with the physical environment of urban areas—will be a crucial scientific and policy discipline. It is one that at least currently is in short supply, since architects, city planners, ecologists, public health specialists, and environmental engineers still operate largely in disconnected disciplines rather than as partners in the quest for sustainable urban development. Moreover, the developing world in particular suffers a greater shortage, just as it does in other crucial areas of public management.

The Environmental Challenge

We are learning fast that the growth of the world economy is not a complete joy. The scale of human economic activity—rising eight times since 1950, and possibly another six times by 2050—is causing environmental destruction on a scale that was impossible at any earlier stage of human history. Economic activity is based heavily on the utilization of natural resources and physical flows such as rainfall, river flow, and of course photosynthesis for our food supply. Yet with the incredible increase of populations and incomes per person, virtually every major ecosystem in the world is now under threat from human activities. The ocean fisheries are being depleted of fish and corals. The scarcity of freshwater for drinking and irrigation is likely to affect hundreds of millions, perhaps billions, of people in the coming decades unless it is much better managed. Climate change will render large parts of the world unfit for agriculture unless we are able to mitigate the man-made climate trends as well as adapt successfully to them. Human destruction of the habitat of other species is leading to a massive extinction of plants and animals. We are causing this in the face of evidence that a decline in biological diversity may render many parts of the world less hospitable, less resilient, and less productive for human beings as well.

It is useful to decompose the human impact on the environment (I) into three parts: the total population (P), income per person (A), and the environmental impact per dollar of income (T). We use the letter T to signify the level of technology. When T is high, the kind of technology being used imposes a high environmental burden (for example, extensive use of land or high emissions of greenhouse gases) per unit of GNP. The total human impact on the environment is equal to the product of population, per capita income, and technology, so that: $I = P \times A \times T$. This is sometimes called the I-PAT (pronounced EYE-pat) equation.

Clearly, the I-PAT relationship signals that a dramatic rise in population and income per person, as we've experienced since 1950 and will experience again till 2050, has a similarly dramatic impact on the environment, unless technology changes in a way to protect the environmental impact. It is useful for us to turn T on its head, and use the letter S to signify the income that is produced per unit of environmental impact. The letter S in this case signifies sustainable technology. A high value of S means that it is possible to produce a high income per unit of environmental impact. The higher the *S*, the lower is the human impact on natural systems. The equation becomes $I = P \times A \div S$.

Now we can restate the environmental conundrum as follows: The world's population is on a business-as-usual track to rise by roughly 40 percent by 2050, and the world's income per person is on a business-as-usual track to rise perhaps fourfold. Thus, $P \times A$, or total world income, is on track to rise roughly sixfold. The human impact on the environment, *I*, with an unchanged set of technologies, would also therefore be sixfold. Since the human impact on the environment today is already unsustainable, a sixfold increase in impact would be devastating and would almost surely feed back to block the rise in world income. In other words, we would never achieve the targeted economic growth because it would be frustrated by environmental catastrophe. Many environmentalists say that we are indeed doomed to lower economic growth as a result, and that in fact the best we can do is to manage an orderly and equitable reduction of per capita income. This school of thought holds that global convergence can only be achieved by reducing the income of the rich countries while making room for some modest rise in income of the poor countries. Convergence, in this view, requires that incomes fall at the top and rise at the bottom.

The alternative strategy is to offset the much-desired rise in *A* with a stabilization of *P* and a rise in *S*, meaning that the world adopts sustainable technologies that have low environmental impact per unit of income. Rather than focusing, as some environmentalists do, on reducing the income and consumption of the rich world, we should focus much more on raising *S*, the sustainability of the world's technologies. There are many examples of high-S technologies, which we will discuss in the coming chapters, including new forms of renewable energy, the capture and storage of carbon dioxide emitted from coal-burning power plants, sustainable fish farming, drip irrigation to maximize the crop output per unit of water input, and improved seed varieties that produce higher agricultural output on a given amount of farmland. In ways such as these, the world can sustain a rising global income without environmental catastrophe.

The Poorest Billion and the Poverty Trap

The last dominant characteristic of our time, and a major threat for the future, is the fact that the convergence club is not yet complete. There are still

large regions of the world, with roughly one billion people, that have not unleashed convergent economic growth. These regions are, by definition, falling further and further behind the world's leaders. In 1820, the richest country in the world, the United Kingdom, had an average income per person that was roughly three times greater than that of the poorest region, sub-Saharan Africa. By 2005, the richest country in the world, the United States, had a per capita income that was roughly twenty times larger than that of the poorest region, still sub-Saharan Africa. For the past generation, sub-Saharan Africa has failed to achieve a rise in income per person.

The growing gap is dangerous in countless ways. It is dangerous for the poor first and foremost, as millions die each year of their extreme poverty. The poorest people are undernourished, without access to safe drinking water, and without reliable access to basic health services. Life expectancy in sub-Saharan Africa is forty-seven years, and less than forty years in several countries, compared with seventy-nine years in the high-income countries. The poorest countries, for reasons we shall see, have the highest fertility rates and the most rapid population growth rate. Much of the expected 2.6 billion rise in global population by 2050 will come from the poorest countries, the places least able to absorb the increase. The poorest countries are the most unstable politically, and the most prone to violence and conflict, often to conflicts that spill over national and regional borders, thereby involving the rest of the world. And the poor, in their desperation to stay alive, are often contributing to massive local environmental degradation by depleting soils of nutrients, overfishing lakes and rivers, and clearing forests to make way for new farmland to absorb a rising population.

The poverty trap is self-reinforcing, not self-correcting. Therefore, overcoming the poverty trap requires special policies and global efforts. There is nothing inevitable about Africa, or any other region, remaining stuck in extreme poverty, yet it will take conscious public efforts in addition to the blind forces of the marketplace to end the poverty trap.

THE STRATEGY OF SUSTAINABLE DEVELOPMENT

Sustainable development means prosperity that is globally shared and environmentally sustainable. In practice, sustainable development will require three fundamental changes in our business-as-usual global trajectory. First, we will have to develop and adopt on a global scale, and in a short period of time, the sustainable (high-S) technologies that can allow us to combine high levels of prosperity with lower environmental impacts. Second, we will have to stabilize the global population, and especially the population in the poorest countries, in order to combine economic prosperity with environmental sustainability. And third, we will have to help the poorest countries escape from the poverty trap. These three basic goals—environmental sustainability, population stabilization, and ending extreme poverty—are of course the essence of the Millennium Promises.

Market forces alone cannot solve these problems. First, market forces alone will not guarantee that the world's scientists and engineers direct their efforts to the development of high-S technologies. Many important technologies will have a huge social benefit for sustainable development but will not produce private-market profitability, so private businesses won't invest in research and development (R & D) to discover and develop them. Second, even when sustainable technologies have been discovered and developed, market forces alone may not guarantee their widespread adoption. We often need special incentives, in addition to market forces, to spur the adoption of sustainable technologies. Third, market forces alone do not guarantee an appropriate pattern of population change within a single country or at the global level. Population policies of various sorts are needed to supplement free-market forces. Fourth, market forces do not guarantee that all parts of the world can meet their basic needs, much less get on a path of convergent growth. Markets leave one billion or more people behind, and the numbers could rise tragically in the future unless we take corrective action.

The Development of Sustainable Technologies

Markets alone will not develop the sustainable technologies that we will need for the twenty-first century. Scientific discovery in general, on which sustainable technologies depend, is a public good that is underprovided by market forces. This is because scientific knowledge is a nonrival good that can be used by anybody without lessening its availability for everybody else. With apples and oranges, more for you means less for me, but you and I can utilize scientific knowledge such as $E = mc^2$ or the structure of DNA without diminishing the availability of the same knowledge for anybody else. Indeed, knowledge works most powerfully when it is widely shared, thereby giving a common base for understanding, action, and development of technological systems. Therefore, science works partly because the worldwide community of scientists makes its discoveries known quickly and freely through peer-reviewed publications, rather than keeping them private and secret. The scientists do not directly capture much, if any, of the economic benefits of their discoveries, nor should they if that knowledge is to have maximum beneficial impact.

Since scientific discovery should remain publicly available, nonmarket means must be used to support the financial investment of resources into scientific discovery. In the past, monarchs were the patrons of scientists. They funded basic science or gave prizes for scientific discovery. Today science must be supported by governments and by philanthropists who give grants to universities and to scientific research centers, both public and private. Private foundations offer awards that also spur effort, most famously, the Nobel Prize. The need for public and philanthropic funding is widely recognized in the United States, even if it is not fully understood by free-market ideologues. It is why the United States, the paragon of free markets, spends upward of $100 billion per year of federal budgetary funds on research and development. Sadly, much of that is squandered, with little benefit, on military R & D for weapons systems, but the federal government still manages to spend $30 billion per year on biomedical research at the National Institutes of Health. Without that effort, the progress of biomedical science would be far behind where it is today, and our life expectancy and well-being would be much lower as well. This public investment in biomedical knowledge has repaid us many times over.

We will need a comparable global commitment to fund R & D for sustainable technologies, including clean energy, drought-resistant seed varieties, environmentally sound fish farming, vaccines for tropical diseases, improved remote monitoring and conservation of biodiversity, and much more. To every dimension of sustainable development there is a crucial technological need, which must be underpinned by investments in basic science. And in every case there is an important need for public finance to spur the new technologies that can enable us to achieve simultaneously the objectives of high global incomes, the end of extreme poverty, the stabilization of the global population, and environmental sustainability.

There is also an important role for a patent system alongside public spending on science. A patent is an exclusive right granted to the patent holder for use of a novel and useful invention, usually for twenty years from the time of filing. Under U.S. and European patent law, abstract ideas—mathematical algorithms, natural phenomena, and laws of nature—are in principle not patentable, though the boundaries between scientific principles and patentable inventions are sometimes murky and controversial. The prospect of winning a patent serves as an important market-based incentive for inventors to develop intellectual property in the first place, and this is the main reason for a patent system. In essence, the patent holder gets to charge monopoly prices during the life of the patent. To mitigate the potential harms of granting such a monopoly, the patent applicant is required to disclose how to make and use the invention so that others can benefit from the advance of knowledge, subject to the exclusivity given to the patent holder.

The policy challenge is to set the right balance between freely available scientific information, which has to be financed by public-sector and philanthropic sources, and privately owned technology, which can be stimulated by the prospect of a patent. This policy challenge is complex, and if done well, leads to a complex and subtle mix of institutions devoted to R & D. These institutions are called innovation systems, and they include the public budget, government research laboratories, private businesses that undertake R & D, academic institutions, government foundations (such as the U.S. National Science Foundation), nongovernmental foundations, individual philanthropists, professional scientific associations such as the U.S. National Academy of Sciences, and more.

When R & D is aimed mainly for general scientific knowledge, the needs of the poor, the global commons, or rapid social uptake, public financing is advantageous compared with reliance on patents. When R & D is targeted mainly for the rich or private use or gradual uptake, the patent-based incentives are relatively advantageous. In general, a healthy innovation system will use a mix of public financing and patents. For global sustainable development, the mix of public financing and private incentives should be harmonized globally to ensure that the needs of the poor and the global commons are properly addressed and financed by shared contributions of the world's governments.

Even when the patent system is clearly useful for sustainable development, such as helping to spur the development of new medicines, steps can be taken to reduce the harmful side effects of the temporary monopoly. For example, in the case of antiretroviral medicines to fight HIV/AIDS, the patent-holding

drug companies agreed to sell products at a reduced or nonprofit basis in the poorest countries, while making patent-protected profits in the high-income markets, an approach called tiered pricing or market segmentation. In this way, the patents in the high-income markets offered incentives for continued R & D, without denying the benefits of the resulting new medicines to the poor.

The Adoption of Sustainable Technologies

It is one thing to develop new high-S technology and quite another to have it adopted on a widespread basis and in a timely manner. The central challenge is to create incentives for firms and households to adopt environmentally sustainable technologies instead of the unsustainable technologies that they now deploy. In many contexts, a high-S technology exists but is more expensive than an environmentally damaging low-S technology. The extra cost of adopting the sustainable technology may be small relative to the large benefit to society of reducing the environmental harm, but the market prices don't send that signal, since the environmental harm is not reflected in market prices and therefore in the incentives facing businesses and households. In those cases, we say that the environmental harms are "externalities," meaning that environmental costs are felt by society but are external to the narrow profit-and-loss calculations of individual businesses and the budget choices of individual households.

Consider a classic example from recent decades. Atmospheric scientists and ecologists began to realize in the late 1960s that sulfur dioxide emitted from coal-burning power plants was mixing with rainfall to produce sulfuric acid. Forests downwind of these factories were being destroyed by the resulting acid rain. Smokestack scrubbers can remove the sulfur dioxide from the flue gas by mixing the gas with lime to produce calcium sulfate, thereby preventing the acid rain. The flue gas desulfurization represents an added cost for the factory, but a cost that is much less than the benefit of saving the forests. The problem is that in a free and unregulated market, each profit-maximizing power plant lacks the incentive to buy a scrubber. Despite the large social benefits, the firm itself would reduce its profits by investing in the scrubber. A public policy to correct the market prices is needed to give the power plants the incentive to buy the smokestack scrubbers.

Four types of policies can be used to align private incentives and society's environmental interests. The simplest is a tax on the environmental harm, in this case a tax on sulfur emissions. In the economics jargon, this "internalizes" the externality. Assuming the tax per ton of sulfur emission is high enough, equal to the high social cost to the forests of an incremental ton of emissions, each factory will buy the scrubber in order to avoid the tax. A second mechanism, the one actually adopted by the U.S. government under the 1990 amendments to the Clean Air Act to fight acid rain, is the issuance of a limited number of permits for sulfur emissions. A company is allowed to emit a certain quantity of sulfur dioxides only if it owns the equivalent number of permits. The permit is tradable and therefore has a market price. If the market value of the permit is higher than the cost of adding a scrubber (and thereby avoiding the emission), the company sells its permit and buys a scrubber. The permit price thereby gives a market-type incentive equivalent to the emissions tax. A third mechanism is an industry performance standard, which in this case might require that all power plants as of a given future date must, by law, dramatically reduce sulfur dioxide emissions. This is the approach that Europe followed under its 1994 Sulphur Emissions Reduction Protocol. The protocol specifies that by 2004 all major combustion sources should reach specified emissions limits. The treaty also says that the parties "may, in addition, apply economic instruments to encourage the adoption of cost-effective approaches to the reduction of sulphur emissions."

A fourth mechanism is zoning, according to which any of these environmental measures (taxes, tradable permits, or performance standards) is applied in certain spatial zones but not in others. The zoning is designed to allow plants to emit more gases where the effects on populations or ecosystems are likely to be small, and to limit the emissions where the damages are likely to be large. The zoning will be designed, for example, to steer polluting industries away from densely populated areas or from especially vulnerable ecosystems. Zoning, or some kind of spatially based policy, is crucial when the social costs of environmental impacts depend strongly on where those impacts occur. In that case, intuitively, the social costs that need to be internalized cannot be captured by a single tax rate, or a single price of a tradable permit, or a single industrial standard.

A pollutant such as sulfur dioxide is an obvious case where private interests and social interests diverge unless market forces are corrected by public policy. Yet there are many other circumstances, some very subtle, where private interests and society's environmental interests are likely to diverge, and thereby to require some corrections to the market forces. The most important of these today, without doubt, is the emission of carbon dioxide by fossil fuel users. Carbon dioxide is the most important greenhouse gas now changing the Earth's climate system. It is not a typical pollutant, because carbon dioxide is harmless and odorless, and doesn't bother anybody except for the fact that it could devastate the planet in coming decades! It requires a market correction, just like sulfur dioxide. Yet the manner for making that correction is much more complex, given the global scale of the problem and the extent to which fossil fuel use is at the core of the modern economy. The challenge is discussed in Chapter 4.

Sustainable Harvesting of Natural Systems

Another major category of human activity that requires the correction of market forces involves the intensity with which society uses natural capital. Human societies tap into innumerable Earth processes that are termed ecosystem services. These processes include the natural growth of forests, which provide fuel wood, construction materials, and more; the hydrological (water) cycle, which is used for irrigation, safe drinking water, industrial production, and more; the growth of fish populations, which are harvested for fish consumption; the regrowth of grasses that feed grazing livestock; the natural fixation of nitrogen in the soils of croplands, which support food production; and countless more. When ecosystems are harvested faster than they can regenerate or recharge, the underlying resources (forest, freshwater, fish, pastureland, soil nutrients) are depleted, sometimes to complete collapse. Under many circumstances, untrammeled market forces will lead relentlessly to collapse rather than to a sustainable rate of resource use.

The risk is greatest if the resource is an unmanaged commons, or open-access resource. The classic example, which gives rise to the term *commons*, is an open-access pastureland, freely available to all who would like to graze their livestock on it. An example of the global commons is the ocean floor beyond national borders, where fishing fleets are free to destroy natural ecosystems as they drag their trawls on the ocean bottom. In these cases, the market incentive is for each individual or business to harvest the resource in question to the point where the market value of the product is equal to the cost of harvesting that extra (marginal) unit. If a ton of fish caught in the trawls is worth $1,000, fishermen will expand their fishing activities as long as the cost of catching the additional ton is less than or equal to the $1,000 of market value. If the value of logging an open forest stand is $1,000 per ton of logs, the forest will be cut as long as the cost of logging the additional ton of trees is less than or equal to $1,000. The rate of harvesting (fishing, logging, or grazing) can dramatically exceed the natural regrowth rate of the natural population of fish, trees, or grasses. In this case, the commons will be depleted. This recognition that an open-access resource will give rise to rapid depletion was famously termed the "tragedy of the commons" by Garrett Hardin in 1968.

Just as with pollution control, there are many mechanisms to limit the rate of harvesting to a sustainable level.

One method is to introduce tradable permits for harvesting, akin to the tradable permits for pollution emissions. The most efficient fishing fleets, which stand to make the highest profits on fishing, will buy more permits. The total catch will be limited to the sustainable yield by design. Many countries, including Australia, New Zealand, Iceland, Canada, and Namibia, use such systems, alternatively called individual transferable quotas or individual fishing quotas. The United States has used a variety of quota systems, including an assignment of fishing rights to individual companies on the West Coast and limits on days at sea on the East Coast. A similar mechanism can apply to logging, grazing, hunting, or comparable uses of a renewable resource. As we might expect, these systems have often languished under intense political conflict over the allocation of the rights.

Another common recommendation is to privatize the commons, a process known as enclosure when it is applied to grazing land. Say the grassland is owned by a rancher with an interest in avoiding overgrazing, since she wants to maximize profit in the long term. The rancher will keep the size of her herd to a sustainable level, compatible with harvesting the grassland at the same rate as its natural regrowth. An open-access tree stand or forest that suffers from excess logging can similarly be stabilized if the commons is privatized. Privatization of the commons may prove to be unwise because of equity considerations, the risk that scarce resources will end up in a few powerful and rich hands while the rest of society is driven to penury. Privatization can also be destructive ecologically, for example, if enclosing the rangeland into small private farm units would impede the vital migratory path of the natural fauna. In many cases of the commons today—the oceans, the atmosphere, land areas of high biodiversity—privatization is barred by practical or ecological considerations.

In these cases, the commons must still be converted from an open-access resource to a common property resource, not a privately owned system. One proven option is community-based management, in which the community, through a local political process, agrees on how to allocate resource use within the community. The community-based organization may decide, for example, on the number of livestock each household is allowed to maintain in the pastures. The entire community, and future generations as well, can benefit compared to living with an open-access status quo. Community-based management of forests, grasslands, water, fisheries, and other common-pool resources has proved to be enormously successful in many contexts and many societies. A fascinating recent success story comes from a pastoralist community in Bayinhushu, Inner Mongolia, which was suffering massive loss of pastureland from overgrazing and soil erosion. In an initiative sponsored by the Chinese Academy of Sciences, the villagers successfully cooperated to reduce herd sizes, reserve part of the common lands for growing animal feed, and seed new grasses. The result was the restoration of degraded pasturelands and a rise in village incomes.

Overcoming the Impatience of the Market

Even when natural resources are properly managed, either through private ownership, permits, or community agreement, social choices might still lead to depletion rather than sustainable management. Consider the following illustration: A lake is filled with a rare fish species that has a market value as food. If the lake is owned as a public commons, and is freely accessible for fishing, the result will be a rapid depletion of the fish population if the costs of fishing are low enough. Now suppose instead that the lake is privately owned (or communally managed) to maximize the economic value of the lake. Will the owner (or community organization) guard against depletion today in order to reap the benefits of selling fish in the future? Certainly the owner will calculate whether it is advantageous to catch more fish today and sell them now, or to catch fewer fish today in order to sell more in the future. Since money in the pocket today is worth more than the same amount in the future (because money today can be invested at the market interest rate and thereby grow over time), the decision will be to keep the fish in the lake only if the market value of the fish stock is expected to increase more rapidly than the rate of interest. If the price of the fish per ton is expected to remain unchanged, and if the fish is a slow-growing species, then the value of the fish in the lake will grow less rapidly than the rate of interest. The profit-maximizing owner will deplete the fish stock and perhaps drive a rare species to extinction, rather than wait to sell more fish in the future. Private (or community) ownership alone will not save the species.

Two subtle issues are at work in this example. The first is that the market price of a species will generally *not* reflect the species' societal value as part of Earth's biodiversity. Market prices do not reflect the value that society puts on avoiding the extinction of other species, only the direct consumption value of those species (for food, aphrodisiacs, pets, hunting trophies, or ornaments). Second, the rate of interest diminishes the incentive of the resource owner to harvest the resource at a sustainable rate. If the value of the resource is likely to grow more slowly than the market rate of interest, the blaring market signal is to deplete the resource now and pocket the money! Since the market rate of interest depends ultimately on the saving decisions and preferences of the current generation alone, without any voice of the future generations, the market rate of interest can give the signal to deplete the resource at the expense of future generations. When the current generation is impatient, that is, it places a high value on current consumption relative to future consumption, the market interest rate will tend to be high and the market signal transmitted to each individual resource owner will be to deplete the resources under the owner's control. In essence, there is a tyranny of the present over the future.

As expected from the theory, slower-growing animals and plants are especially endangered today. Consider as an example one major category: slow-growing megafish. Their slow growth makes them a "poor investment" even in managed fisheries, and their large size makes them an easy prey. A new megafishes project has identified a number of species that are endangered (Chinese paddlefish, Mekong giant catfish, Tanganyika lates, and the pallid sturgeon, among others). Large land animals are in similarly desperate straits.

Once again, public policy can intervene to align private interests with sustainable development and, specifically, with the interests of later generations unrepresented in the market today. The overharvesting of a natural forest or a rare species can be banned by setting aside protected land or marine areas, and by banning hunting, fishing, or trading of particular species. Both methods are widely used, though imperfectly, and both still fall to the onslaught of illegal harvesting and free-market ideologies. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), adopted in 1963, is the preeminent international trade treaty to protect endangered species by regulating and in some cases banning trade in endangered species. The treaty agrees on a hierarchy of endangered species: (1) those that are threatened with extinction and therefore banned for trade except in exceptional circumstances; (2) those that are endangered and therefore regulated; and (3) those that are protected in at least one country, a country that asks for cooperation from the other signatories. There are now 172 members of the convention, and these members agree on the classification of species and the follow-up actions.

Toward a Sustainable Population

Controlling population growth on our planet is the second great challenge of sustainable development. However, there is also a tyranny of the present when it comes to population growth. Parents often have many children in order to ensure the parents' old-age security, a decision that may well come at the expense of the children's own well-being. After all, an impoverished family cannot really provide for the nutritional, health, and educational needs of six or seven children, yet impoverished parents may have that many children for their own benefit, a subtle form of exploitation of future generations by today's generation. Similarly, in places where land ownership is communal and land is redistributed according to family size, each family might well overproduce children because it expects the community to transfer land to it as a result. If natural resources (such as trees for fuel wood) are held communally, this, too, can result in a choice of excessive family size. Each family will not take into account the social costs of added children to the sustainability of the commons.

A household's decision on fertility also depends on widespread cultural norms, on the availability of contraception in public health facilities, on the educational opportunities and costs for children, and on many other matters that are determined by public policy. All of this is to say that the decentralized decision making of individual households can easily lead to excessive population growth, at rates that jeopardize the physical environment and the well-being of the children (and later generations). On the other hand, public policies designed to promote a voluntary reduction of fertility rates can have an enormous effect, benefiting both present and future generations.