Chapter 6

The Relation Between Net Carbon Emissions and Income

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ISSUES OF GLOBAL climate change frame one of the most important debates and concerns about the environment today. Unlike most other environmental topics, the issues surrounding global climate change transcend continents and by their very nature seem to defy local, even national governmental solutions. Worse, there is no universal agreement about the problem itself. Serious scholars have data on both sides of the question of global warming, and others have interpreted existing facts in myriad ways. The public seems to believe that the Earth is warming, unnaturally, but public perception, although politically important, is not always scientifically accurate. If all this were not enough, there is even disagreement about the impacts of global climate change, assuming it to be real. One camp is concerned that melting ice and

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rising sea levels will drown some cities; others claim there is no evidence of global warming; some even say the Earth is cooling. At the same time, some scholars argue that the Earth's warming might be good for humanity—longer growing seasons, more food, and less cold, which kills.[1]

I will not address the question of whether there is or is not unnatural warming of the planet, whether it is good or bad if there is or is not global warming, and whether it is or is not caused by emissions of carbon dioxide or any other gas, solid, or liquid. These questions are interesting and no doubt important, but they are not the focus of this chapter.

Instead I will address several basic issues that appear to be fundamental in context of the debate about global climate change. These include the following:

- What is the correct way to measure carbon and other global warming gas emissions? by country? in total? per capita? per dollar of gross domestic product?
- Do economies that grow and become richer emit more or less than poorer economies?
- Is gross or net gas emissions the correct way to think about global warming?
- How does the United States compare with the rest of the world in carbon gas emissions?

The Complexity of Net Carbon Emissions

There is considerable concern in the environmental movement about the relation between economic activity and what is called global warming.[2] Human economic activity leads to the burning of fossil fuels and plant matter, releasing carbon dioxide. Numerous additional human activities release other gases, such as methane and chlorofluorocarbon compounds. In turn, increases in carbon dioxide, methane, and other carbon compounds in the atmosphere are argued to cause the Earth to retain additional heat from the sun and thus warm in an unnatural way. This has led to many proposals to control the emissions of greenhouse gases, notably the Kyoto Protocol.

Even though the protocol sometimes recognizes that net emissions, not gross emissions, are the relevant concern, popular discussion and great chunks of academic discourse seem blindly focused on gross emissions. Little attention is paid to the substantial chunks of carbon sequestered in trees and forests, farms, crops and groundcover, buildings, furniture, clothes, landfills, and other organic possessions.

The net amount of carbon in the atmosphere depends on the difference between the amount of carbon sequestered in sinks and the amount emitted by sources. The terrestrial stock of carbon is increased by the growth of carbon sinks. A sink is an object, like a tree (or group of objects, like a forest), in the terrestrial sphere that stores more carbon in a given year than it emits. The terrestrial stock of carbon is decreased and the atmospheric stock increased by burning carbon sources such as fossil fuels, usually done to create energy. A source is an object or activity in the terrestrial sphere that emits more carbon into the atmosphere than it stores. So a growing forest would tend to be a sink, and a forest fire would tend to be a source.

Many carbon stocks vary from year to year as either a sink or source. For instance, landfills, although growing in volume and hence storing carbon, also emit methane to the atmosphere. Careful study is required to determine whether they are a source or sink in a given year. Similarly, growing trees add to the stock of solid carbon or increase the stock of gaseous carbon depending on their growth and decay rates.

As an example, carbon may be sequestered by trees and deposited into landfills. The initial sequestration occurs in a given year, either as increased tree volume or wood production. The transfer of carbon to the landfill is merely a location change in stored carbon and, as such, is not sequestration but rather a movement of storage location.

Carbon sequestration is the process whereby gaseous carbon is removed from the atmosphere and stored in the terrestrial sphere.

Sequestrations can take place either as deliberate human practices, such as removing carbon dioxide from the air and cooling it for transport to some place for some other purpose (dry ice is an example) or as the result of natural processes or human-induced activities with unintended consequences. The warming of dry ice would, for example, return the carbon to the atmosphere as gas.

Oceans

The chemistry of carbon states is complex and controversial, but there are a number of agreed-upon principles. For instance, the ocean holds about fifty times more carbon than the atmosphere in the form of dissolved inorganic and organic carbon (Intergovernmental Panel on Climate Change 2000, 1.2.1.2, 31). In the ocean, carbon is sequestered by plantlike phytoplankton, which in turn is consumed by sea animals. Some of this carbon rains down toward the ocean floor as waste and dead organisms. Bacteria feed on this particulate organic carbon and produce carbon dioxide, which dissolves in the water. The rest of the detritus ends up on the sea floor (Preuss 2001).

Evidence suggests that the ocean removes three times more carbon—and holds nineteen times more in storage (U.S. Department of Energy 1999)—from the atmosphere per year than the terrestrial system. Carbon also cycles between land and ocean. The ocean gains carbon in the form of runoff from the terrestrial system, and carbon is removed from the oceanic reservoir through the process of sedimentation of organic remains and inorganic carbonate shell material. However, it is the variability in carbon flux between the atmosphere and land that primarily explains the annual variability in atmospheric carbon.[3] In other words, although the store of carbon and the annual flux of carbon are both greater for the ocean than the terrestrial system, most of the atmospheric variability over time is because of flux from or to land.[4]

Fossil Fuels

Carbon cycles from the terrestrial sphere to the atmosphere primarily when fossil fuels storing carbon are used in energy production. Some of the fossil fuels used for energy include petroleum, coal, and natural gas. Consider the United States, the main focus of this research. Between 1950 and 1970, U.S. energy consumption per person rose from 229 million to 334 million BTUs. Between 1970 and 1999, the change was much less drastic, with a consumption of 354 million BTUs per person in 1999. Between 1949 and 1999, energy consumption per dollar of gross domestic product (GDP) fell by half, from 20.63 thousand to 10.92 thousand BTUs per (1996) dollar of GDP (U.S. Department of Energy 2001, Table 1.5, 13). Energy use itself has also become more efficient with respect to carbon emissions. Over the century, natural gas has replaced coal in industrial, commercial, and residential energy use to become the second-biggest energy source, behind petroleum. In 1999, natural gas use produced 1.32 pounds of carbon dioxide per kilowatt-hour, whereas coal produced 2.09 pounds (U.S. Department of Energy and U.S. Environmental Protection Agency 2000).

Agriculture

Energy consumption is a primary source of airborne carbon emissions, but there are other sources that emit carbon naturally via methane, including livestock, rice paddies, and wetlands. Livestock include cattle (dairy and beef), swine, poultry, and others, but cattle alone are responsible for more than 90 percent of methane produced by enteric fermentation, a process in which microbes residing in animal digestive systems break down the feed consumed by the animal. Enteric fermentation accounted for 19 percent of all methane produced by the United States in 1998, exceeded only by the amount produced in landfills (U.S. Environmental Protection Agency 2000). Between 1927 and 2000, the number of milk-producing cattle dropped by more than half, from 21.4 million to 9.2 million. During that same time, milk production nearly doubled, from 89 billion to 167 billion pounds because of the fourfold increase in productivity of the cattle (U.S. Department of Agriculture 2001). In order to understand correctly how enteric fermentation has changed because of increased production technology, further research must be done to determine how the larger quantities of feed necessary to provide higher milk production have increased emissions per animal.

Although cattle and other livestock are a source of carbon and methane emissions, these animals also stand to be significant sources of carbon sinks via the carbon stored in their bodies. Raising livestock reduces the amount of airborne carbon. The emissions have to be compared with the sequestrations.

Livestock plays another role in methane emissions. The decomposition of organic animal waste (manure) in an anaerobic environment produces methane, but the amount of methane produced depends on the style of manure treatment or management. Liquid systems tend to encourage anaerobic conditions and produce significant quantities of methane, whereas solid waste management produces little or no methane. Between 1990 and 1998, emissions from this source increased by 53 percent because of the swine and dairy industries' shift toward larger facilities, which tend to use liquid management systems.

A main focus of this research agenda is to expand on the link between income and carbon emissions. In this regard, the relationship between agricultural and overall economic activity stand to be important. For example, the planting of trees is affected by changes in income and stages of economic growth. During the first part of the twentieth century, the number of U.S. farms was increasing. Between 1910 and 1935, the number of farms grew by 6 percent, before the beginning of a steady decline that persisted into the 1990s (U.S. Department of Agriculture 2001). In 1950, 1.202 billion acres of the United States were used as farmland. The area used for farming increased to a high of 1.205 billion acres in 1955, then decreased steadily until today. In

1999, only 947.44 million acres of land were used for farming. A large portion of U.S. farmland was built on previously forested lands, and many of these abandoned farms reverted back to forest. Between 1982 and 1997, 1,108,400 net acres of prime farmland (considered prime farmland in 1982) were converted to forest (U.S. Department of Agriculture, National Resource Conservation Service 2000). During the same time period, land areas with biomass containing the lowest carbon content, pastureland and rangeland, were reduced (U.S. Department of Agriculture, National Resource Conservation Service 2000).

Wetlands

Wetlands are most likely the largest natural source of methane emissions into the atmosphere. Methanogenic bacteria found in wetlands produce methane through anaerobic decomposition of organic materials. Between 1986 and 1997, a net of 644,000 acres of wetlands were drained. The Fish and Wildlife Service reported to Congress that the estimated wetland loss rate in 1997 was 58,500 acres annually (U.S. Fish and Wildlife Service 2001). Although the environmental benefit of preserving wetlands is left for other studies, draining wetlands may reduce the annual amount of methane produced (Augenbran, Matthews, and Sarma 1997).

Forests

The level of atmospheric carbon decreases when terrestrial stocks of carbon grow over time. The primary terrestrial sinks are forest and soil. The forest ecosystem stores carbon in four major forms: trees, soils, understory, and the floor. “Trees” includes all above- and below-ground portions of all live and dead trees. This includes the merchantable stem, limbs, tops, cull sections, stump, foliage, bark and root bark, and coarse tree roots. “Soils” includes all organic carbon in mineral horizons to a depth of one meter, excluding coarse tree roots. “Understory” includes all live vegetation except trees. "Floor" includes all dead organic matter above the mineral soil horizons except standing dead trees: litter, humus, other woody debris, and so on.

Many variables affect the forest carbon stock. Forest tree volume increases as a result of new plantings or growth in existing trees. Forest tree volume declines as a result of harvesting or burning. Several variables affect the growth of trees, including age, weather, fire suppression, and understory biomass. When old growth forests are allowed to grow for long periods, carbon flux declines to essentially zero. Fire suppression, beginning after the 1930s, has had a large impact on carbon sequestration. Between 1919 and 1929, more than twenty-six million acres of wild land burned on average each year. During the next decade, almost forty million acres burned each year. As a result of enormous expenditures on fire suppression, the average annual burn area between 1990 and 1999 was 3,647,597 acres, a reduction of more than 90 percent (National Interagency Fire Center 2001). Between 1994 and 2000, U.S. federal agencies spent $4,334,840,600 on fire suppression. Fire suppression, and its resulting addition to carbon sequestration, would seem to be positively influenced by the growth in U.S. income.[5]

Another factor affecting carbon sequestration is the rate of harvest of existing forests. The rate of harvest is influenced by the demand for wood used for fuel or wood products. Harvested wood no longer accumulates carbon; however, it can act as storage for differing periods of time. Wood harvested for fuel acts as carbon storage until the wood is burned and the carbon is released. Wood harvested for wood or paper products may exist as carbon storage indefinitely as treated or sealed wood may decay at a very slow rate.

Wood harvesting and clear-cutting for agriculture grew as the United States was settled in the eighteenth century. As wood fuel was replaced with fossil fuels midway through the nineteenth century, harvest rates slowed in many regions and wood for fuel consumption nearly disappeared, only to reemerge during the Depression and the oil shocks of the 1970s. By the 1950s and 1960s, many forest regions began to accumulate carbon faster than it was harvested, resulting in overall carbon sequestration. Between 1976 and 1996, harvest rates remained constant in the Northeast and fell dramatically in the Pacific Northwest and Rocky Mountains. On the other hand, a resurgence in fuel wood use and increasingly intensive use of forests for wood products caused harvest rates in the South (already the highest in 1976) to increase by more than 50 percent.[6] The net effect was a 12 percent national increase in removal of forest between 1976 and 1996. This is independent of the flux in the forest carbon stock attributable to tree growth.

Technology in wood harvesting also affects carbon sequestration. The efficiency of industrial wood harvesting improved over time, so that more wood was removed per hectare and less left as slash (dead vegetation). Whether this affects carbon sequestration positively or negatively depends on the end use of the harvested wood. If the harvested wood is being used to produce wood products, the slash will decay at a relatively faster rate than those products. If the harvested wood is to be burned for energy, the slash will store carbon for a longer period than the harvested wood. And because the majority of wood is used for products rather than fuel, especially in richer economies, the reduction in slash over time has had a positive impact on carbon sequestration.

Another important carbon sink that has been growing over time is woody biomass outside of forests. Savanna ecosystems are composed of two major competing types of biomass: grassland formations and woody plants. Woody plants include shrub-steppe, desert scrub, wood land, or forest. Over the past century, woody plants have occupied an increasing percentage of land. In the United States, this woody encroachment stores most of the carbon contained in nonforest, noncropland biomass. Many theories have been proposed as to the growing encroachment, including fire suppression, overgrazing, and nitrogen deposition. The annual burn area of the United States has declined by 95 percent since 1850, significantly reducing one source of carbon emissions (Pacala et al. 2001). As a result, woody plants, which historically were burned, are covering a much larger area. Changes in soils and microclimate accompanying long-term heavy grazing may have shifted the balance more to woody plants better adapted to nutrient-poor soils (Archer, Boutton, and Hibbard 2000). This growth previously was unaccounted for in studies of the U.S. carbon budget.

Soil

Soil organic carbon makes up about two-thirds of the carbon pool in the terrestrial biosphere (Allmaras et al. 2000). This carbon is in the form of plant, animal, and microbial residues in all stages of decomposition. By contrast, the only significant vegetation that stores carbon is located in forest biomass and woody plants. Soils, on the other hand, store carbon regardless of local vegetation (Intergovernmental Panel on Climate Change 2000, 1.2.1.2). Temperate and tropical forests (not located in the United States) store more carbon in the local vegetation than the local soil. However, biomass in most other areas contains less carbon than the corresponding soil. Hence there is more carbon stored nationally in soil than in vegetation. It is therefore important that a study of carbon sequestration account for soil-bound carbon in addition to carbon stored in biomass.

Carbon Emissions

Total emissions of carbon dioxide in the United States from all sources for the years 1900–1999 in carbon equivalents are plotted in Figure 6.1,[7] which reveals that carbon emissions have been on the increase, basically without interruption, for the entire past century.[8]

Figure 6.2 corrects total emissions for changes in population and reports emissions per capita for the past century.[9] Emissions per capita in the United States, while growing some in the first half of the twentieth century (most of the growth occurring in the first twenty years of the century), have been flat or declining for the past quarter-century.

Figure 6.3 plots the emissions per capita in the United States versus

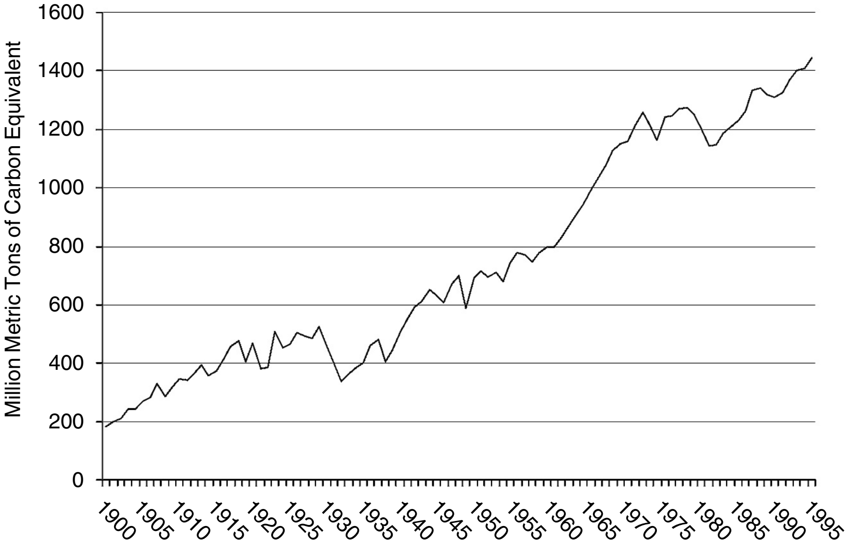

Figure 6.1 Total Emissions of Carbon Dioxide in the United States, 1900–1999
Source: Marland, Boden, and Andres (2002)

income for the period of 1929 through 1996.[10] Emissions rise with real income, up to about $5,000 per person per year; thereafter, they are relatively flat. As Figures 6.2 and 6.3 reveal, emissions per capita are not currently on the rise in the United States, that is, not over the past twenty-five years.[11] Combining this fact with the observation that total emissions are on the rise means population growth or exporting activities account for all of the rise in carbon dioxide emissions in the United States over the past quarter century, and the greatest portion of the growth in emissions for the entire past one hundred years. This suggests that policies directed toward lowering carbon dioxide emissions should take extra care, because the issue is population growth, not growth in carbon emissions per person.

Another way to analyze carbon emissions is to compute emissions per dollar of GDP. This, in a way, measures how efficiently an economy uses its energy to create output. Carbon emissions per dollar of real

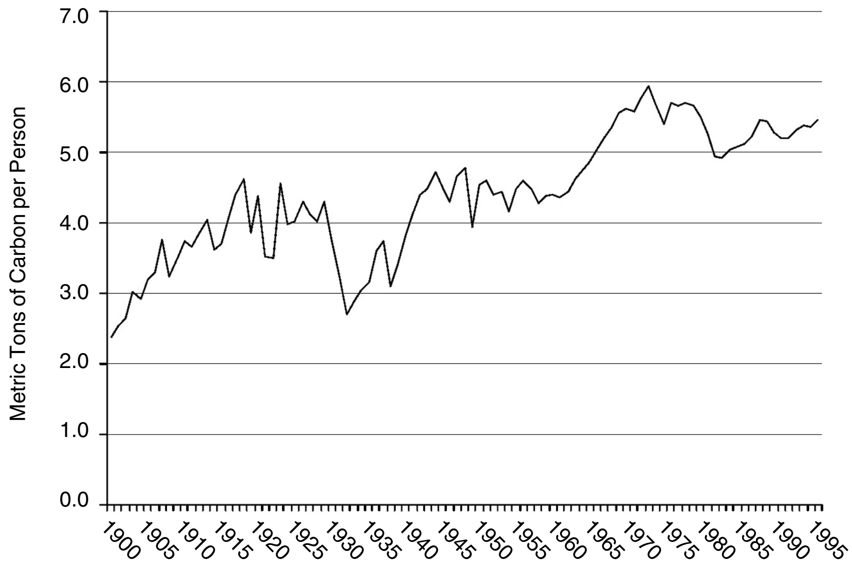

Figure 6.2 Total Carbon Emissions per Person in the United States, 1900–1999
Source: Marland, Boden, and Andres (2002)

GDP have been on the decline, almost continuously, for the past half century in the United States. Figure 6.4 plots the U.S. energy consumption per dollar of GDP (1996 terms). This steady decrease is due to increasing energy efficiency in the production of its national consumption and to the switch from manufacturing to services in national production.[12]

Visual examination of the data charted in Figure 6.4 suggests and statistical analysis confirms a prediction of declining emissions per capita once the income level is sufficiently high.[13] U.S. GDP per person is now in the low $30,000-per-person range, which is near the critical value where emissions per capita should start to decline.[14] Hence, per-capita carbon emissions can be expected to decline if economic growth continues.

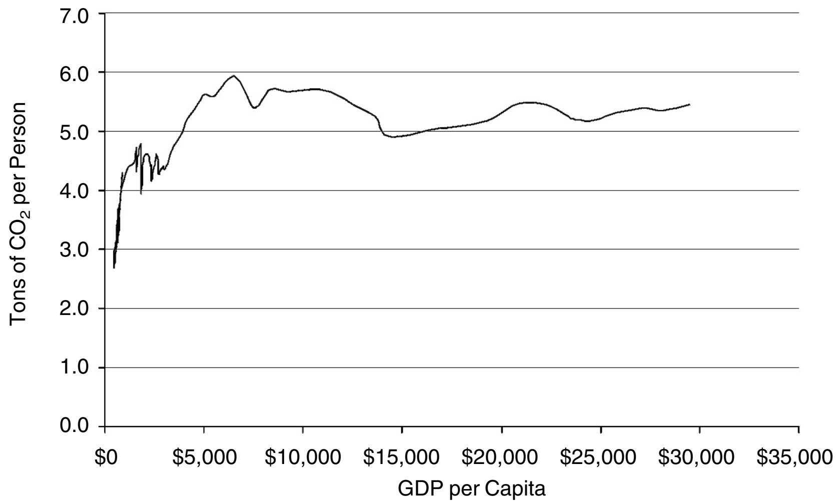

Figure 6.3 Gross Carbon Emissions per Person and Income in the United States, 1929–1996
Source: U.S. Department of Commerce, Bureau of Economic Affairs 2002

Carbon Sequestration

Just as income affects carbon emissions, it affects carbon sequestration. Consider carbon sequestered in U.S. forests, for example. As a result of increased forest acreage, total carbon sequestration in forests was up about 47 percent between 1952 and 2000 (see Figure 6.5).[15] Annual forest sequestration per capita was nearly constant from 1960 to 1970, increased sharply through 1980, but decreased thereafter (see Figure 6.6).

Standard statistical modeling techniques show that national forest acreage grows with income, but at a decreasing rate. Acreage per person is a function of real GDP and the relationship is positive, but somewhat complex. Income and forest acreage are positively linked, and carbon sequestrations grow with income. Thus, there is evidence that income and carbon sequestrations, via forests, are positively linked. This evi-

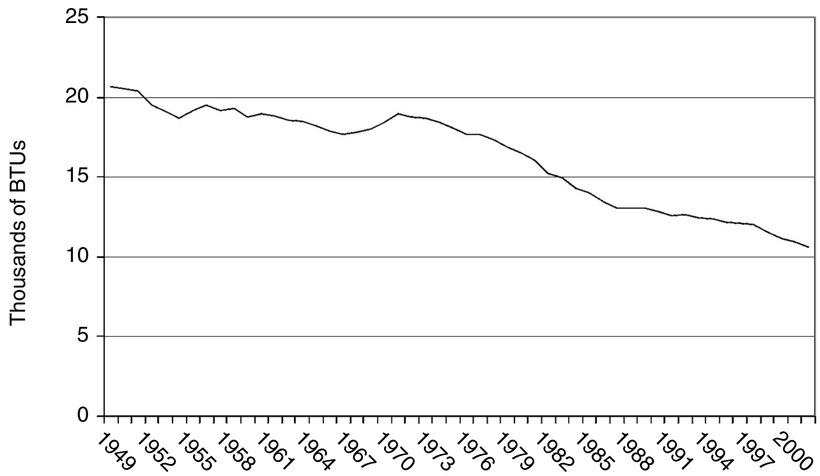

Figure 6.4 U.S. Energy Consumption Corrected for GDP
Note: In terms of 1996 dollars
Source: U.S. Department of Energy, Energy Information Administration 2002

dence is good news for those who fear global warming. Higher incomes are linked with larger amounts of earthbound carbon sequestrations.

There are other sources of sequestration besides trees. As agriculture has become more productive, the amount of cropland in temperate regions has fallen, and agricultural practices are the most important variable in the accumulation of soil organic carbon. In 1997, 25 percent of the 1.5 billion acres of U.S. nonfederal land were considered cropland. The conversion of natural vegetation to cultivated use inevitably leads to an immediate loss of carbon in soil. Some estimates suggest that cultivated croplands in the United States lose about 2.7 terragrams of carbon per year (Gebhart et al. 1994). This loss in carbon can be attributed to reduced inputs of organic matter, increased decomposability of crop residues, and tillage effects that decrease the amount of physical protection to decomposition (Post and Kwon 2000). Tillage-induced changes of perennial grasses to annual crop species reduce root biomass and inputs of carbon from roots to soils. Fluxes in carbon

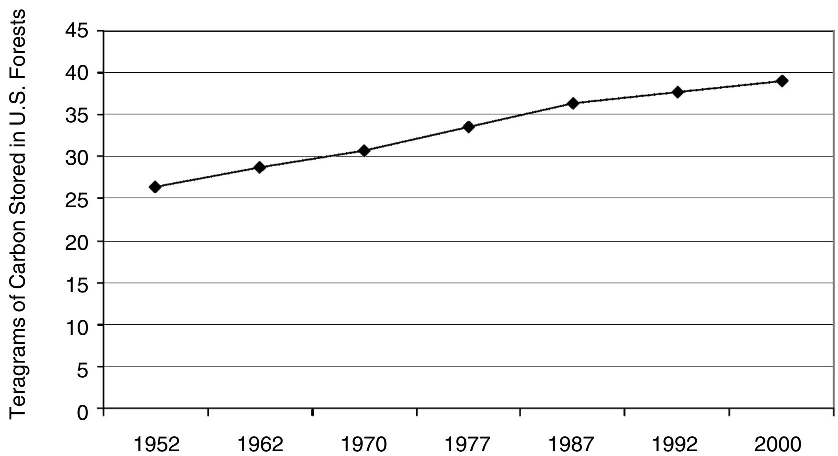

Figure 6.5 Total Carbon Storage in U.S. Forests
Source: Birdsey and Heath (1995)

are therefore tied to the area of land that is taken in and out of agriculture each year, as well as to the technology of agriculture used on existing croplands.

Because the acreage of total U.S. farmland has declined over most of the past century and because cropland is typically a net source of carbon emissions, abandoning cropland stands to reduce net emissions irrespective of whether the land reverts to forest or other significant biomass. In fact, the U.S. Conservation Reserve Program, established to reduce water and wind erosion on more than 45 million acres of erodible and environmentally sensitive cropland, restored 21 percent of soil organic carbon lost during tillage in just five years. Cropland treated this way has the potential to sequester 45 percent of the 38.1 terragrams of carbon emitted annually into the atmosphere by U.S. agriculture (Gebhart et al. 1994).

Lower tillage intensity (less mixing and stirring of the soil) has also decreased net carbon emissions from agriculture. As incomes rise and technology develops, agriculture has naturally moved toward a system

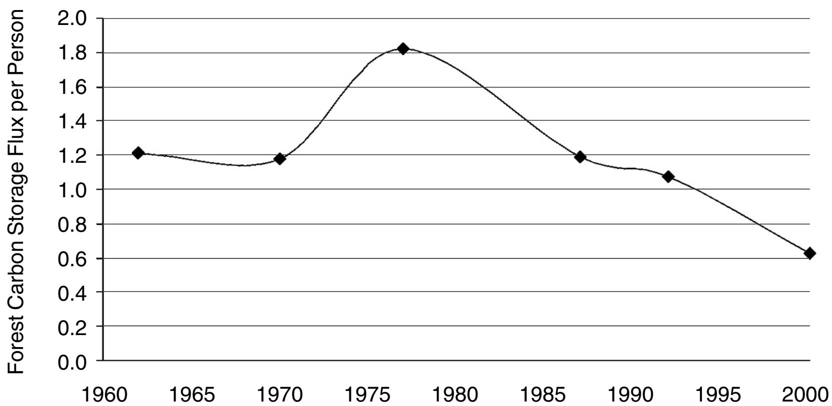

Figure 6.6 Annual Forest Carbon Sequestration per Person in the United States

Note: The vertical scale is in metric tons of carbon flux per million people.

Source: Birdsey and Heath (1995)

that favors fewer net carbon emissions from soil use (see Post and Kwon 2000).

The atmospheric stock of carbon also decreases when the carbon stock in anthropogenic sinks grows. Such sinks include landfills, buildings, manufactured agricultural products, automobiles, manufactured wood products, and living bodies. Wood and agricultural products store a significant amount of carbon for varying amounts of time, depending on end use.

Approximately 16 percent of all discarded municipal solid waste is incinerated. The remainder is disposed of in landfills. Forty-one percent of U.S. landfill volume is taken up by paper and paperboard, 7.9 percent is food waste, and 17.9 percent is yard waste (Micales and Skog 1998). Therefore the majority of cellulose and hemicellulose in landfills originates from forest and agricultural products. This represents a large amount of carbon being sequestered each year. The U.S. Forest Service has estimated that none to 3 percent of the carbon from wood and an average of 26 percent of the carbon from paper is potentially released

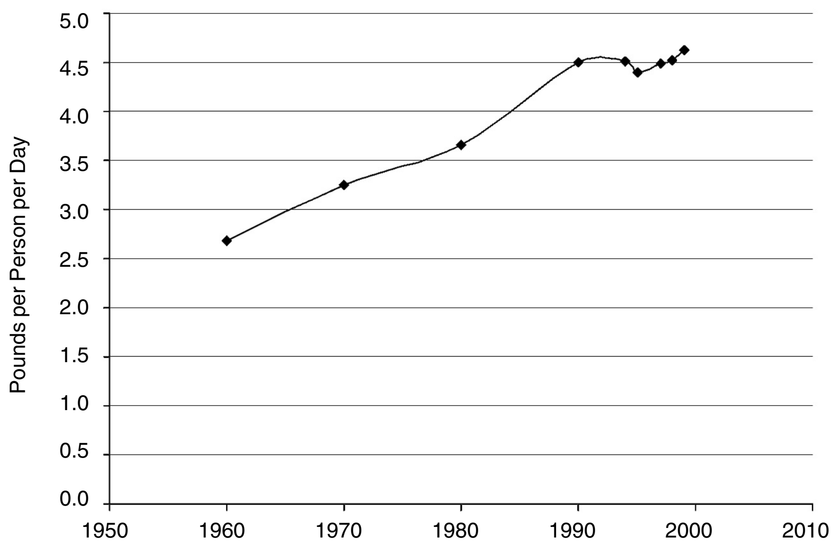

Figure 6.7 U.S. Landfill Storage per Person per Day over Time
Source: U.S. Environmental Protection Agency (2001)

into the atmosphere as carbon dioxide and methane once the material has been put into landfills (Micales and Skog 1998). Moreover, the percentage susceptible to release has fallen over time as waste has been deposited in landfills that seal the waste and limit the amount of decay from oxygen. Though this slows the decay rate of wood products and increases stored carbon, it produces more methane relative to carbon dioxide. Because methane has a greater impact on global warming potential, the flux in net carbon emissions must be weighted by this effect.

The portion of garbage recovered or recycled is increasing, but this increase is dominated by the increase in the total amount of garbage created. The United States is increasingly creating garbage and disposing of it as landfill. The stock of carbon being buried, assuming a constant fraction of garbage is carbon, is rising. Landfills are a carbon sink, depending upon the amount of methane released. Figure 6.7

reveals that Americans are increasingly accumulating resources in landfills, although at what appears to be a decreasing rate.

The amount of carbon stored in buildings, automobiles, animals, and persons is a function mainly of the growth in the total number of those goods and organisms over time. Because the flux is positive for many or all of these categories, a reasonable assumption is that carbon storage has risen accordingly.

For example, animal and human populations have been growing in size so that they can meaningfully affect net terrestrial carbon. The growth in the size and weight of human population embodied more carbon in the past century. This carbon flux ranges from 0.025 million metric tons of sequestration in 1901 to 0.042 million metric tons in 1991. The numbers are small relative to overall emissions, but the intuition is correct: Human population growth has contributed slightly to carbon sequestration in the form of living matter. The carbon flux attributable to growth in the stock of cattle is similar. Between 1921 and 1999, the average annual carbon flux attributable to the growth in the stock of cattle is 0.045 million metric tons of carbon per year.[16] The average sequestration attributable to hogs is much smaller, equivalent to 0.004 million metric tons of carbon per year.[17] Additional analysis of animal carbon stores follows later in this chapter.

There is also carbon transfer between land and the land-based aquatic system that occurs within terrestrial waterways, such as reservoirs and rivers. Although the total carbon storage in the terrestrial aquatic system (lakes, rivers, reservoirs, and so on) is small relative to that of forests and soil, its growth rate in carbon storage is significant enough that it may account for more than 5 percent of the carbon sequestered within the United States between 1980 and 1990 (Pacala et al. 2001). Rivers also export a small quantity of sequestered carbon to the sea. By some estimates, the total export of dissolved inorganic carbon and particulate organic carbon to the sea may account for another 5 percent of U.S. carbon sequestration.

Net Emissions

The primary point is that carbon naturally and unnaturally fluxes and flows between solid and gaseous states. But how does human economic activity influence the rate of flux and the stores of carbon in each of these two states? On the one hand, carbon emissions grow with income—richer economies consume more carbon energy sources—but carbon storage in the terrestrial sphere probably grows as well as richer people accumulate wealth in the form of material things, many of which are carbon-based. The question thus becomes: Which grows faster as incomes increase, emissions or sequestrations? Do the causes and effects of the income growth when the economy is relatively poor—dirty energy consumption, growth in agriculture, and deforestation—spur a net surplus of sources over sinks? Does economic growth when the country is relatively richer—the shift to service industries, afforestation, and less dirty energy use—lead to a decrease in the disparity or perhaps a net surplus of sinks over sources? According to so-called environmental Kuznets curve literature (see Chapter 3 of this book), pollution increases with industrial and income growth until some turning point. After this inflection, additional income growth leads to enhanced environmental quality.

International treaties such as the Kyoto Protocol propose to set caps on carbon emissions in order to limit the growth of atmospheric carbon. Because this will almost surely reduce energy production in the short term, this could cause a contraction in national income. At a minimum, the growth rate of income will slow. If it is true that net carbon emissions rise and fall with income, this policy might have the perverse effect of keeping a country at an income level at which carbon sources are greater than carbon sinks. In the end, a cap on emissions might actually increase the amount of airborne carbon. And to those worried about global warming, this might make the world warmer.

Several statistics point to the possibility that economic growth in the United States may lead to a decrease in net carbon emissions. First, carbon emissions from energy production by developed and transition economies fell from the 1980s to the 1990s. During the same time period, emissions increased by more than 50 percent for low-income nations. Second, emissions from the second largest source, land-use change such as conversion of forests to cropland, diminished from the 1980s to the 1990s (Intergovernmental Panel on Climate Change 1990).

Table 6.1 lists total emissions and sequestrations as computed in this study for the United States over the period 1962 through 1998, and Figure 6.8 plots net emissions per capita. The chart suggests that net emissions were rising until the early 1970s, fell until the early 1980s, and have been rising since. This pattern follows intuition about the link between net emissions and income. The 1970s experienced slow or even negative growth in the United States, whereas growth and economic activity picked up in the 1980s and into the 1990s.

Figure 6.9 plots net emissions per real GDP per capita. Statistical analysis of these data are only suggestive. On the one hand, total net emissions seem to be negatively linked with GDP (higher GDP reduces total net emissions). At the same time, net emissions per person are either flat or rising. The exact statistical relationships are complex so a clear picture does not emerge. However, it is certainly the case that the growth of total net emissions has slowed, and detailed statistical analysis suggests that total net emissions of carbon will start falling when income exceeds about $35,000 per person in 1996 terms.[18] This is just above the current level of income per capita in the United States today. This analysis suggests that the United States is nearing the apex of the environmental Kuznets curve for net carbon emissions. All told, these data suggest additional economic growth should bring declining net emissions of airborne carbon per person within the United States. The United States appears on the road to being a net carbon sink and this is in spite of its great use of energy and large level of emissions. The data say that rich people consume—but they also accumulate.

Table 6.1
U.S. Emissions and Sequestrations of Carbon

	Total Emissions	*Total Sequestrations*	*Net Emissions*	*Net Emissions per Capita*
1962	828.582	426.1	402.5	0.219974
1963	872.512	441.6	430.9	0.231992
1964	909.595	438.7	470.9	0.249881
1965	944.815	454.8	490.0	0.256451
1966	996.098	462.1	534.0	0.276011
1967	1035.509	478.8	556.7	0.284742
1968	1077.381	476.8	600.5	0.304260
1969	1128.385	480.6	647.8	0.325011
1970	1152.145	470.1	682.1	0.335498
1971	1159.217	530.7	628.6	0.303907
1972	1211.838	553.7	658.1	0.314468
1973	1259.274	591.8	667.5	0.315820
1974	1214.83	594.5	620.3	0.290774
1975	1164.477	636.0	528.5	0.245266
1976	1244.362	671.9	572.4	0.263110
1977	1248.602	709.5	539.1	0.245327
1978	1281.887	711.3	570.6	0.256920
1979	1292.801	724.9	567.9	0.252872
1980	1262.782	696.8	566.0	0.249843
1981	1217.507	718.8	498.7	0.217334
1982	1156.118	707.9	448.2	0.193487
1983	1159.142	620.8	538.4	0.230280
1984	1203.247	681.6	521.6	0.221197
1985	1215.008	685.3	529.7	0.222624
1986	1216.079	653.6	562.5	0.234254
1987	1259.909	624.9	635.0	0.262088
1988	1328.802	583.7	745.1	0.304760
1989	1337.681	626.7	711.0	0.288055
1990	1314.394	636.7	677.7	0.271671
1991	1321.685	616.6	705.0	0.279610
1992	1327.371	657.7	669.7	0.262601
1993	1388.431	591.8	796.6	0.309019
1994	1419.436	643.8	775.6	0.297945
1995	1417.295	580.1	837.2	0.318551
1996	1456.189	603.8	852.4	0.321375
1997	1484.944	600.3	884.6	0.330343
1998	1486.801	590.6	896.2	0.331626

Note: See Utt, Hunter, and McCormick (2002) for details on computational methods.

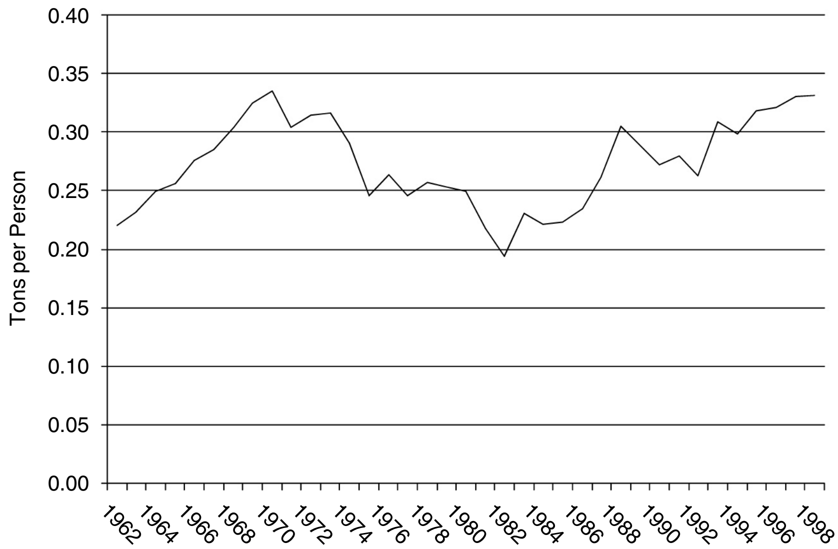

Figure 6.8 Net Carbon Emissions per Person in the United States
Source: See Utt, Hunter, and McCormick (2002, 43–47) for computations and technique.

International Comparisons

The United States is often characterized as the world's greatest polluter, and in the context of global climate change, the United States is regularly seen by the world as dragging its feet on dealing with the question of global warming, carbon emissions, and climate change. This section reports some data for international comparisons.

Data on gross carbon emissions are available for most countries for a long time span.[19] Figure 6.10 uses these data to plot the annual emissions of carbon dioxide per person for the world for the period 1950 through 1996, and the results are profound. Gross or total global carbon emissions per capita are essentially constant over the past thirty years. And, as previously discussed, they have actually declined in the United States over this period. Although total emissions have grown, again, the

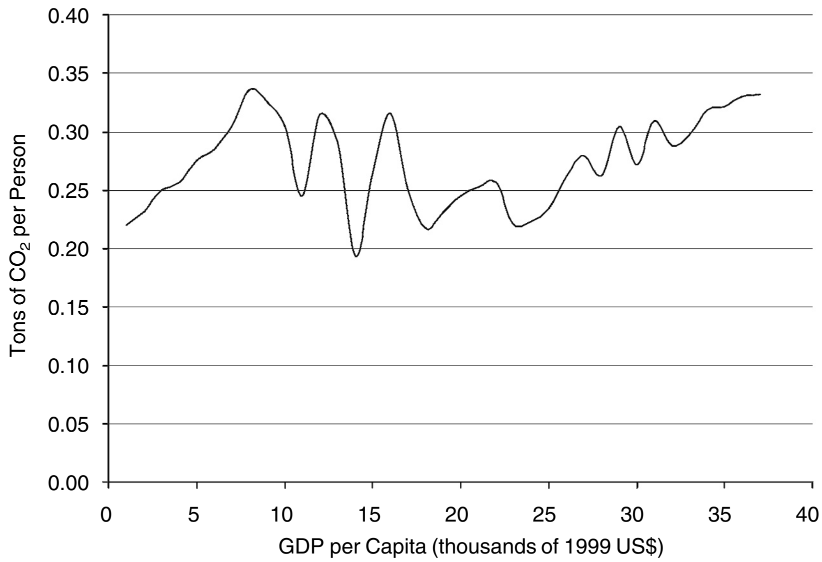

Figure 6.9 Net Carbon Emissions per Real GDP per Person, 1962–1998
Source: Utt, Hunter, and McCormick (2002, 47)

problem is not with individual carbon emissions per se, but with the fact that there are more people.

Putting all these pieces together, given the fact that global gross emissions of carbon per capita are at worse flat, but are quite probably decreasing, global warming, if it is a social problem, is a problem of population growth, not of wealthy individuals and growing economies. Quite the opposite is true. If there is a policy prescription, it is that we should pursue policies that spur economic growth and wealth accumulation. Less net carbon emissions will follow.

It is also noteworthy that the fertility rates seem to decline with income (see Becker and Barro 1988; Chapter 5 of this book). Thus richer societies also procreate at a slower rate. However, richer people tend to be healthier and longer-lived. Hence, the relation between carbon emissions, population, and income begs further study.

The United States is often portrayed as the world's greatest polluter

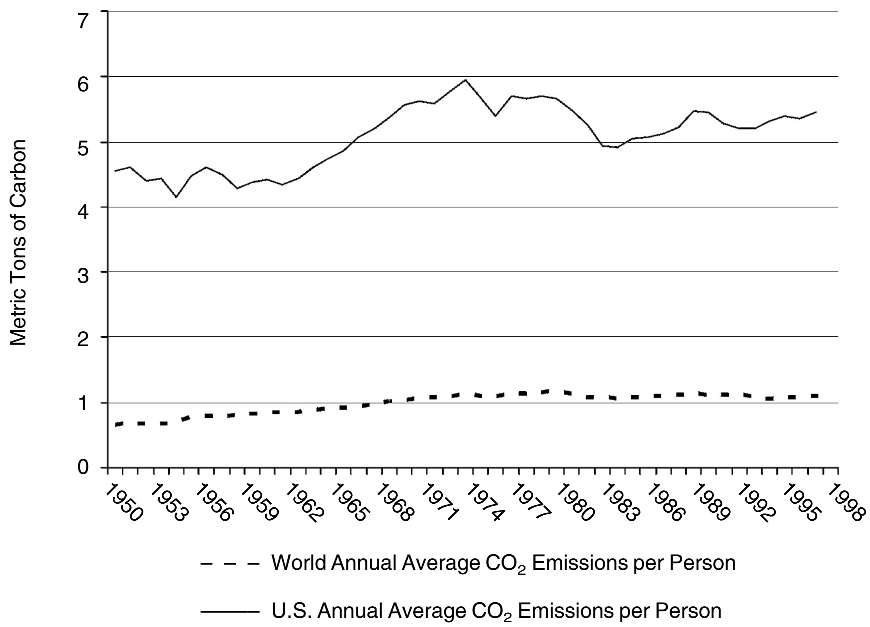

Figure 6.10 World Annual Emissions of Carbon Dioxide per Person
Source: Carbon Dioxide Information Analysis Center 2002

because its gross emissions per capita are more than four times the world average. Figure 6.11, however, tells a slightly different story. The ratio of U.S. gross emissions relative to the world is declining. As a member of the world, the United States is emitting a smaller and smaller portion of the gross carbon emissions into the atmosphere on a per-capita basis. Whatever else might be true, neither U.S. nor world carbon gas emissions are growing on a per-person basis. Moreover, relative to the rest of the world, the United States is emitting less and less per person.

Closing Thoughts

Do increases in economic activity lead an economy to take carbon out of the air? There is certainly reason for hope that the answer to this

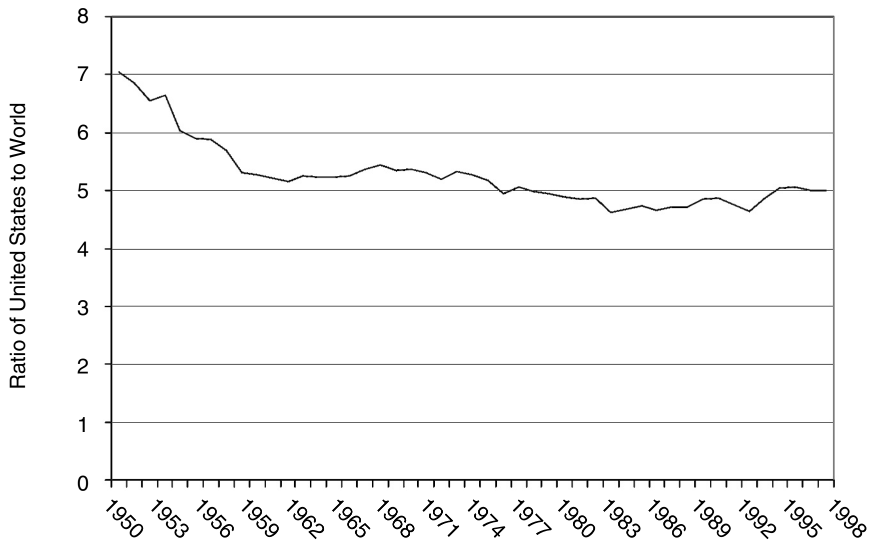

Figure 6.11 U.S. Gross Carbon Emissions per Person Compared with the Rest of the World
Source: Carbon Dioxide Information Analysis Center 2002

question is yes. Based on direct evidence from the United States coupled with indirect evidence from the rest of the world, it does appear that richer economies take more carbon out of the air than poorer ones. Hence, a unidimensional focus on carbon emissions—looking only at what comes out of the tailpipes of automobiles, for example—stands to result in errors in analysis and policy. Results presented in this chapter bolster the argument that richer people also suck substantial amounts of carbon out of the air into animals, trees, landfills, buildings, and other material possessions. Statistical analysis in this chapter forecasts that the growth rate of net carbon emissions per person will soon be negative in the United States, as long as income continues to grow. If that trend continues—and there is every reason to believe that it will—the United States is likely to become a carbon sink. Based on this evidence, the Kyoto Protocol and other regulations on economic activity may do more harm than good. Regulators of carbon emissions should take great care not to kill the goose that lays the golden eggs. The results presented in this chapter indicate that net carbon emissions will decline if economies grow and people get richer. The analysis supports the view that higher incomes are associated with a better natural environment. Fascination with emissions controls and the Kyoto Protocol is somewhat hard to understand in this context.

One simple but profound fact remains. Even while U.S. and global total gross emissions are on the rise, there is little or no growth in total or gross carbon emissions per person in either the United States or the world. Moreover, taking sequestrations into account, there is even less of an issue with carbon emissions.

Notes

1. There are many places where one might go to investigate these contentions in detail. A sampler includes http://www.pewclimate.org; http://www.globalchange.org; http://www.epa.gov/globalwarming; http://www.ipcc.ch; http://gcmd.gsfc.nasa.gov; http://www.co2science.org; and Julian Simon (1995, 1999).
2. Again, let me emphasize that I borrow heavily here from earlier, joint work with Utt and Hunter (see Utt, Hunter, and McCormick 2002).
3. Intergovernmental Panel on Climate Change (2000, 1.2.1.3, 32) lists five sources in support of this contention.
4. The rate of carbon uptake is limited by the solubility of carbon dioxide in seawater and by the slow transfer between the surface and deep waters (Intergovernmental Panel on Climate Change 2000, 1.2.1.3, 32). The limited solubility of carbon dioxide can be pictured by considering how quickly a carbonated beverage goes flat after being exposed to air. Carbon is stored more effectively at greater depths; however, carbon cycles very slowly within the ocean. Waters circulate between surface and deep layers on varying time scales from 250 years in the Atlantic Ocean to 1,000 years for parts of the Pacific Ocean (U.S. Department of Energy 1999).
5. Technological advances in silviculture have likely promoted additional carbon sequestration over time. Because the technology and science of silviculture are positively affected by economic growth, it is reasonable to assert that income growth is linked to carbon sequestration on these grounds as well.

6. Data provided by Brad Smith, Forest Inventory and Analysis, U.S. Forest Service.
7. A carbon equivalent measures the amount of carbon in a compound. For instance, the atomic weight of carbon dioxide is 44, of which carbon is 12. Therefore, a ton of carbon equivalent carbon dioxide actually weighs 3.6667 tons. Put differently, 3.6667 tons of carbon dioxide contain one ton of carbon.
8. There are two exceptions, the early 1930s and the early 1980s. The first is likely traced to the Depression. The second is more mysterious.
9. Remember that carbon dioxide, although by far the largest component of total carbon emissions into the atmosphere, is not the only one. There is, for instance, methane. Moreover, in the context of the normative problem of global warming, there are noncarbon compounds that most scientists claim also warm the climate. These include, for instance, nitrous and nitric oxides. Worse yet, again in the context of the normative analysis of global warming, not all carbon molecules act the same. Many scientists argue, for instance, that carbon in methane has twenty-one times the global warming potential of carbon in carbon dioxide. Carbon in certain chlorofluorocarbon compounds has, by some estimates, 11,000 times the potential. Hence, in the analysis presented here some caution is in order, for only emissions of carbon in carbon dioxide are being measured. Other sources, a relatively small portion of the global warming situation, are omitted here.
10. This period was chosen because of data limitation on GDP for the United States.
11. This visual conclusion is supported in the statistical analysis as well. The full results are reported in Utt, Hunter, and McCormick (2002).
12. Without doubt a great deal of additional investigation is warranted here. Specifically, a cross-sectional analysis seems appropriate to disentangle the impact of changing income from the changing structure of output, and whether or how these latter two effects are related.
13. See Utt, Hunter, and McCormick (2002) for more details.
14. See Utt, Hunter, and McCormick (2002) for the details.
15. These data are not measured each year, but sporadically within the time frame: 1952, 1962, 1970, 1977, 1987, 1992, and 2000.
16. This excludes methane emissions emanating from cattle, but those emissions are already included in alternate versions of the U.S. carbon budget. What is generally left out of the budget is the flux attributable to the growth in stock.

17. What this discussion leaves out is the long-term fate of human and animal carbon. Some forms of this carbon are stored long-term in various forms, whether as products or as matter in landfills or graves. This long-term sequestration has not been accounted for in previous studies.
18. Again, the detail of methods and computations can be found in Utt, Hunter, and McCormick (2002).
19. See Carbon Dioxide Information Analysis Center, "National Fossil-Fuel CO2 Emissions," at http://cdiac.esd.ornl.gov/trends/emis/tre_coun.htm.

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