

1989

## **Toward the Inclusion of Environmental Factors in the Concept and Measure of National Income.**

George Edward Foy Jr  
*Louisiana State University and Agricultural & Mechanical College*

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**Toward the inclusion of environmental factors in the concept  
and measure of national income**

**Foy, George Edward, Jr., Ph.D.**

**The Louisiana State University and Agricultural and Mechanical Col., 1989**

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**Toward the Inclusion of Environmental Factors in the  
Concept and Measure of National Income**

**A Dissertation**

**Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Doctor of Philosophy**

**in**

**The Department of Economics**

**by**

**George E. Foy Jr.  
B.A., Yale University, 1979  
M.S., Louisiana State University, 1986  
August 1989**

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Dissertation Abstract: Toward the Inclusion of Environmental Factors  
in the Concept and Measure of National Income

This dissertation uses Sir John Hicks' concept of income as a guide to integrate environmental factors into the concept and measure of national income.

Chapter 1 introduces Hicks' concept of income as the maximum amount which one can consume in a given period and still be as well off at the end of the period as he was at the beginning. This basic idea of sustainability requires accounting for the net depletion of all capital consumed in current production.

Chapter 2 documents recent trends in natural resource use to demonstrate that exclusion of the depreciation of environmental capital from NNP is a pressing practical issue. Chapter 3 provides a general framework for the analysis of production functions with natural capital service flows, Hicksian income and wealth, and income measurement in the case of natural capital service flows. Chapter 4 critiques the present treatment of environmental factors in income and wealth measures from the perspective of Hicksian income.

Chapters 5 and 6 critique proposals for modification of the economic accounts to more fully reflect environmental factors. Chapter 5 considers aggregation methods which value the depreciation of environmental capital in monetary terms. Chapter 6 considers disaggregated methods which require physical measures of changes in marketable natural resource stocks and nonmarketable environmental capacity linked to the economic accounts.

Chapter 7 provides an empirical example of environmental accounting by estimating several capital consumption allowances for loss of Louisiana wetlands in 1986 due to oil and gas activity. Two different methods are used to estimate physical damage functions of wetlands due to oil and gas activity. The first method relies on ecologists' consensus estimates of oil and gas induced wetland loss over a 24 year period. The second method uses a time series statistical model of annual wetland loss

and oil and gas activity over 32 year period. These physical damage functions are then combined with measures of wetland values from other studies to form estimates of the capitalized environmental loss to Louisiana and the United States of 1986 oil and gas activity in the Louisiana wetlands.

Chapter 8 is the summary of the dissertation.



## Chapter 1: Introduction

The fundamental purpose of this dissertation is to determine a proper conceptual basis of a national income measure that closely approximates Hicksian income, evaluate the current income measures by that criterion, and suggest improvements. In particular, the aim is to integrate environmental factors into the concept and definition of income.

Gross national product (GNP) is defined to be the dollar value of total production of final goods in an economy in a period of time; this is identically equal to the sum of incomes generated plus indirect business taxes and the capital consumption allowance. GNP is at the heart of macroeconomic analysis and real world policymaking; it is the basic magnitude in most macro models, and growth in GNP is the number one economic goal of virtually all of the world's nations. However, the concept and measurement of GNP is beset with enormous unsolved problems, some old and some new. The primary reason why it is beset with enormous problems is that GNP is a numerical proxy for an important, but inherently vague concept. As Simon Kuznets has noted, the terms in the definition of GNP such as value, production, and final goods are "circumscribed by a wide area of reference accepted by common agreement and a substantial periphery subject to controversy and treated differently from time to time, country to country, and investigator to investigator."<sup>1</sup> The inevitable lack of precision in these concepts makes the attempt to approximate them with numerical measures very difficult, but the relevance of the numerical measures depends on how well they approximate important economic concepts. What is easily measurable may be irrelevant.

We will now state the central meanings of income, wealth, and production, and indicate some of the difficulties in devising analytical measures for these vague concepts. Extensive discussion of these topics will follow in later chapters. Income is a

vague concept; it is used to refer to a psychic flux of satisfaction which is the final output of economic activity. There are many kinds of satisfactions that are incommensurable, and we have no unit that corresponds directly to addition of real numbers. Furthermore, the means of satisfaction change with time and place. Hicks saw the central meaning of income as a guide to prudent conduct in practical affairs. Thus a man's income is the "maximum value which he can consume during a week, and still expect to be as well off at the end of the week as he was at the beginning."<sup>2</sup> In other words, Hicksian income is a psychic flux of satisfaction which does not impair its source; thus it is the psychic flow of sustainable consumption. Of course, this flow is not directly measurable, so proxies such as final goods or dollars are used as analytical similes for income. Many conventions must be established in order to subject the concept of income to measurement.

The concept of Hicksian income presupposes the concept of wealth which can be understood as a stock from which a stream of satisfactions can be derived. The critical difference between wealth and income is that wealth is a stock which yields future satisfaction, while income is a flow which yields satisfaction over a period of time. Wealth is also a vague concept. There is no one kind of wealth or wealth unit that allows aggregation of all stocks that provide future satisfactions, and the concept of wealth may evolve over time. Conventions are also needed in order to measure wealth. For example, can wealth include physical stocks like a machine, as well as metaphysical knowledge, like human capital? Is food on a plate a proxy for wealth or income?

The concepts of income and wealth imply a concept of production. Production is the process of using some particular wealth forms, such as labor, capital, and natural resources, to create goods and services that in turn provide a psychic flux to individuals. Production transforms wealth forms into a flow of income. Many decisions must be made in building analytical measures for production. For example, what is a 'final good' or product? Can total production be approximated by market production? Does nature

produce output? Decisions on such questions must be made and have been made in determining past and current definitions of wealth, income, and production.

The fact that many arbitrary decisions must be made in determining the meaning of these concepts and their analytical measures may cause one to question the whole endeavor of accounting for national income and wealth. However, as Kuznets said, "The choice is not between retaining national income estimates and discarding them; and it is not even between not having and having widespread public discussion of these and related estimates. Society has always needed and searched for a commonly agreed upon yardstick by which to measure the success of its economic activity."<sup>3</sup> Many relevant economic concepts such as income and wealth are amorphous, yet there is a need for appraisal measures. Carefully considered, but to some extent arbitrary, conventions are unavoidable in the establishment of analytical measures for vague concepts. The measure will always be a compromise between empirical possibility and accuracy in depicting the concept.

Today's conventions and analytical similes may not be accurate tomorrow because the world is qualitatively evolving through time. Thus it is not surprising that, throughout the last several hundred years, economists have debated the proper boundary lines and conventions in definitions of wealth and income and later in national income accounting. For example, an important recent controversy in the measurement and interpretation of wealth concerns the treatment of environmental capital. Society may not want to seriously impair the source of future income for short term benefit. This interest in sustainability is shown in the measurement of net national product or NNP, which is equal to GNP minus the consumption of reproducible capital. NNP is the practical simile of Hicksian, or sustainable income. However, as we will see in detail later, currently accepted measures of NNP and other aggregate economic statistics are inadequate as income measures because they do not fully account for losses of environmental capital necessary for long run income flows. If this exclusion is severe

enough, we need revised analytical measures that serve the purpose of more accurately representing the concept of sustainable income.

Analytical similes that represent measurement of income and wealth attributable solely to environmental factors will be called environmental accounting. The environmental accounts together with traditional economic accounts would provide analytical measures for the concept of full sustainability. We need to determine feasible guides to fully sustainable income either through modification of existing economic accounts to incorporate environmentally related income and capital consumption, physical environmental accounts with links to economic accounts, or some combination of the two.

In some accounting frameworks, environmental capital is limited to stocks of natural resources sold on commodity markets such as petroleum or timber. However, the concept of environmental capital used in this thesis is broader, encompassing both marketable and nonmarketable natural resources; both petroleum and the capacity of a wetland to assimilate wastes are types of environmental capital. These stocks of environmental capital yield flows of natural services such as energy conversion, biodegradation, nutrient formation, etc. The flows of these services are, in turn, inputs in natural production functions which generate services desired by humans such as energy, waste assimilation, and fertilization. For example, the service of hurricane protection from wetland ecosystems is a function of various biological services which themselves are provided by environmental capital. As is the case with environmental capital, some environmental services are marketable while some are non-marketable. Economic activity uses and may deplete environmental capital. To the extent this depletion may reduce sustainable income through its effect on production, environmental capital should be included in analytical measures of wealth, and its loss accounted for in sustainable income.

The structure of this dissertation is as follows: In Chapter 2, we discuss recent worldwide trends in the use of environmental capital to demonstrate that concern with its inclusion in economic accounting is well founded. In Chapter 3, we provide a general framework for the analysis of production functions with natural capital service flows, Hicksian income and wealth, and income measurement in the case of natural capital service flows. In Chapter 4, we present the current treatment of environmental capital stocks and service flows in the national balance sheets and income accounts. This demonstrates the need for better incorporation of environmental factors into the economic accounts.

In Chapters 5 and 6, we survey and critique modern proposals for modification of the economic accounts to more fully reflect sustainability. In Chapter 5, we consider aggregation methods which value the depreciation of environmental capital in monetary terms for direct inclusion in subsidiary series of the present accounts. This allows the calculation of one aggregated monetary figure as a measure of sustainable income. Since there is considerable debate on the possibility of monetary valuation of natural resource capital, chapter 6 considers disaggregated methods which require physical measures of marketable natural resource stocks and provide indicators of changes in non-marketable environmental capacity linked to the economic accounts. These disaggregated methods do not allow the calculation of a single monetary figure as a measure of income.

In Chapter 7, we provide an illustrative empirical example of environmental accounting by estimating several capital consumption allowances for the loss of Louisiana wetlands in 1986 due to oil and gas activity. Two different methods are used to estimate physical damage functions of wetlands due to oil and gas activity. The first method relies on ecologists' consensus estimates of oil and gas induced wetland loss over a 24 year period. The second method uses a simple time series statistical model of annual wetland loss and annual oil and gas activity (measured as wells completed or

thousands of barrels of oil equivalent) over a 32 year period. These physical damage functions are then combined with estimates of wetland values from other studies to form 1986 capital consumption allowances. These allowances provide estimates of the capitalized environmental loss to Louisiana and the United States of 1986 oil and gas activity in the Louisiana wetlands.

In chapter 8, we present a summary of this dissertation.

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<sup>1</sup>Simon Kuznets, National Income and Its Composition, 1919-1938 (New York: National Bureau of Economic Research, 1941), p. 3.

<sup>2</sup>J. R. Hicks, Value and Capital, 2nd edition. (Oxford: Clarendon Press, 1965), p. 172.

<sup>3</sup>Simon Kuznets, National Income: A Summary of Findings (New York: National Bureau of Economic Research, 1946), pp. 135-36.

## **Chapter 2: Trends in Use of Natural Resources**

### **1. Introduction**

The last 50 years have seen a great increase in the power of technology and the scale of the human economy relative to the environment. The human economy is now causing major changes in stocks of natural resources and the capacity of environmental systems necessary for future income flows. These changes must be linked to the national economic accounts in order to provide adequate measures of sustainable income. This chapter will present some basic trends in human natural resource use to show the importance of including environmental factors in measures of economic performance. It is not a comprehensive overview of world depletion and pollution problems, nor does it show what environmental factors are included in the present accounts. In Sections 2 and 3, we consider trends in the use of marketable and nonmarketable natural resources respectively.

### **2. Marketable Natural Resources**

Current income levels depend on a wide array of biological and geological capital; thus it is important to account for depletion of this capital in assessing sustainability. Accordingly, we will present trends in the following broad categories of marketable natural resources: nonfuel minerals and fossil fuels, agriculture, forests, and fisheries.

Industrial societies depend on a continuing supply of nonfuel minerals. Between 1965 and 1985, annual world production of aluminum, copper, lead, and iron ore increased by 142, 73, 23, and 38 percent respectively.<sup>4</sup> Annual world commercial



energy production increased fourfold from 1950 to 1986.<sup>5</sup> It is difficult to determine the net depletion (new discoveries minus extraction) of minerals and energy because reserves are complex functions of physical availability, technology, and prices. However, it is important that net depletion of this natural resource capital be considered in calculations of sustainable income.

Agricultural products are critical natural resources. Total world cereal production has increased from 1,556 million metric tons in 1979 to 1,801 million metric tons in 1984.<sup>6</sup> While farming is theoretically renewable, modern agriculture is dependent on large nonrenewable inputs of pesticides, fertilizers, and energy. The necessity of vast quantities of nonrenewable inputs combined with alarming rates of soil erosion and water mining raise serious questions about the sustainability of agriculture and point to the need for accounting systems that warn of unsustainable use. Agricultural or pasture and permanently degraded to desert like conditions continues to grow at an annual rate of 6 million hectares.<sup>7</sup> Desertification is a complex process with natural and anthropogenic origins, but a significant part of this process is due to population increases in semi-arid regions, deforestation, exhaustion of aquifers, and salinization of farmlands due to excessive irrigation and poor drainage. The formerly irrigated area that is now being abandoned is about equal to the area currently being reclaimed and irrigated in the world today.<sup>8</sup> In the United States, 13% (55 million acres) of U.S. cropland exhibits erosion rates exceeding soil loss tolerance levels by up to twice its value. Another 20.6 million hectares exceed the tolerance level by more than two times.<sup>9</sup> The United States Department of Agriculture reports that the water table in the U.S. is falling by at least 6 inches, and in some cases up to several feet, per year on over 14 million of the 36 million acres irrigated with groundwater.<sup>10</sup>

Total world production of roundwood increased 20 percent from 2,531 million cubic meters in 1972 to 3,042 million cubic meters in 1983. The bulk of the increased harvest (498 of 511 million cubic meters) came from South America, Asia, and Africa.<sup>11</sup>

Timber is by far the most important commercial product from natural forests, particularly less developed countries. Wood exports from the tropics increased on average by 7.1% in volume and by 17% in value annually during the 1970's.<sup>12</sup> The vast majority of this is from natural forests rather than managed tree farms.<sup>13</sup> Thus, where forests are not permanently destroyed, second growth timber is usually inferior to the virgin cutting. Although forests are potentially renewable, there is concern for their long-term viability due to current deforestation rates in some areas. In the 1980's, Tropical forests in Asia, Africa, and America are being deforested at a rate of 11.3 million hectares per year. This is approximately a 0.58% annual deforestation rate.<sup>14</sup> There is still controversy over the rates and projected rates of deforestation in the Tropics. Some deforestation may be beneficial, while other forest loss may leave land permanently degraded. For sustainable income measures, what matters is that we account for depletion and transformation of biological capital when calculating current income increases from more wood use.

World marine fishery harvests have risen from 71 million metric tons in 1970 to 76 million metric tons in 1983.<sup>15</sup> Although fish are potentially renewable resources, current harvest rates from natural sources may not be sustainable. The U. N. Food and Agriculture Organization has assessed the status of 19 principal fisheries in the northwest Atlantic. Fish stocks in four fisheries were depleted, while 9 fisheries were fully exploited. In the early 1980's, 11 major oceanic fisheries, 6 in the Atlantic and 5 in the Pacific, had been depleted to the point of collapse. Among these are the Atlantic cod, haddock, Atlantic herring, Pilchard, Salmon, Halibut, King Crab, and Anchoveta.<sup>16</sup> It is not always clear whether fish stock declines are due to natural forces, or to overfishing, pollution, or some combination of these factors. Certainly overfishing is one important factor, and it renders fish populations more vulnerable to other stresses. Here it is also important that economic accounts record in some way whether current income from fishing is sustainable or at the expense of biological capital.

### 3. Nonmarketable Natural Resources

Information on net depletion of marketable natural resources is necessary but not sufficient for assessing the sustainability of current income flows. This is because extraction and consumption of marketable natural resources inevitably use nonmarketable environmental capital due to the first and second laws of thermodynamics. While service flows from nonmarketable natural resources are 'free goods' if used below capacity levels, excessive use will generate high costs for present and future human economies. We will consider some effects of human economic activity on the following nonmarketable environmental capital: atmosphere and climate, global nutrient cycles, marine environments, and biological diversity.

The earth's atmosphere and climate is being altered primarily by the use of energy and nonfuel minerals. There are at least three major areas of concern: acid rain and other air pollution, global warming, and depletion of the stratospheric ozone layer. There are four regularly monitored groups of air pollutants: carbon monoxide, nitrogen oxides, sulfur oxides, and suspended particulate matter. The main source of anthropogenic carbon monoxide emissions is the incomplete combustion of fossil fuels, particularly gasoline or diesel. Nitrogen oxides arise from transportation and stationary fuel combustion, while sulfur oxides are byproducts of stationary fuel combustion, particularly high-sulfur coal. There are important natural sources of suspended particulates such as volcanoes, but fuel combustion and other industrial processes create significant amounts, including toxic trace elements. Emission levels and ambient levels of carbon monoxide and nitrogen oxides have decreased in the developed countries since the mid 1970's mainly due to auto emissions control programs. Sulfur oxides in the air have decreased in developed countries mainly due to regulation of coal-fired power plants. Although progress has been made in developed countries, emissions of these pollutants have increased in the last five years in most large cities in

the Third World.<sup>17</sup> Particulate pollution levels have stabilized or decreased in many areas of the world in the last decade, but there is increasing concern about toxic trace metals in the atmosphere.

Ozone, another important pollutant, is not emitted directly in large quantities. Rather, it is formed by the reaction of sunlight with hydrocarbons, nitrogen oxides, and oxygen.<sup>18</sup> The primary anthropogenic sources of volatile organic compounds and nitrogen oxides are industrial processes, transportation, and stationary power sources.<sup>19</sup> Tropospheric ozone levels are generally high throughout much of the industrialized world, and ozone concentrations known to cause plant damage occur over wide areas of the United States.<sup>20</sup> Ozone concentrations of 0.10 to 0.25 parts per million have caused significant yield reductions in many important plant species such as sweet corn, soybeans, cotton, alfalfa, pines, maples, and sycamores.<sup>21</sup> Ozone is one of the multiple causes of air pollution damage to ecosystems and human health.

The human economy is also polluting the air with toxic trace metals such as arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, nickel, silver, tin, vanadium, and zinc. The production of most of these metals along with fossil fuels has vastly increased in the last 50 years. There was little anthropogenic emission of trace metals due to their low volatility until the advent of high-temperature processes, particularly smelting and fossil-fuel combustion. These activities have increased atmospheric concentration and deposition of trace metals harmful to man and other organisms. Scientists have measured trace metal depositions in remote environments such as the North Atlantic Ocean and Antarctica, rural environments not directly affected by local anthropogenic emissions, and urban areas directly affected by local anthropogenic emissions. Values for metal deposition in urban areas were from 100 to 10,000 times more than those from North Atlantic precipitation and up to 1,000,000 times higher than those from Antarctica. Metal deposition in rural areas was 10 to 100 times higher than those from North Atlantic precipitation.<sup>22</sup> Although our knowledge of trace

metal deposition is still very imperfect, the evidence indicates that the waste capacity of environmental systems is being stressed by current emission and deposition of toxic trace elements.

Acid rain is a popular term for the atmospheric deposition of acids from pollutants, particularly sulfur dioxides and nitrogen oxides from fossil fuel combustion. These pollutants are converted in the atmosphere to sulfuric and nitric acids which are removed from the air by wet and dry deposition processes.<sup>23</sup> A normal pH for rain is 5.6 to 6.8 on a logarithmic scale. Now broad areas of eastern North America and northern and central Europe experience precipitation with annual pH averages from 4.0 to 4.5<sup>24</sup> Deposition in this range is harmful to material structures, ecosystems, and human health.

Atmospheric transport of sulfur compounds and other acidifying components has led to extensive regional acidification of water courses in areas such as Southern Scandinavia and parts of eastern North America that are near industrial sources. Acid precipitation causes changes in freshwater chemistry by mobilizing heavy metals in soils, rocks, and sediments. These are subsequently leached by drainage and enter surface and ground water. Elevated concentrations of cadmium, lead, aluminum, manganese, zinc, copper, and nickel (these last five being toxic to living organisms in the 0.3 to 10 ppm range) have frequently been observed in acidified lakes.<sup>25</sup> There is also evidence that acidification reduces the diversity of plant plankton and affects a number of other organisms in the aquatic food web.

The recent destruction of trees in North America and Europe has been linked to acid rain and other pollutants. At the end of 1985, at least 7 million hectares in 15 European countries had been affected by Waldsterben, or forest death.<sup>26</sup> Widespread forested areas in the United States may be in the early stages of ecosystem decline.<sup>27</sup> The precise mechanism of damage is unknown, and no single hypothesis can explain the wide variety of destruction. However, the scientific consensus is that the primary causes are atmospheric deposition of air pollutants such as acid rain, ozone, trace

metals, and other substances. Secondary causes of the recent forest death are insects, known forest pathogens, drought, and frost.<sup>28</sup> The full effects of air pollution on forests are unknown at this time, but forested areas provide many environmental services such as watershed maintenance in addition to wood products.

Global warming of the atmosphere is a serious problem. There is now a general consensus in the scientific community that the world's climate is likely to grow warmer as a result of increasing levels of carbon dioxide, and other trace gases like methane, chlorofluorocarbons, nitrous oxide, and ozone. A doubling of global carbon dioxide concentration is projected to increase global temperatures by 3.5 to 4.2 degrees Centigrade; this could occur within the next 50 to 100 years.<sup>29</sup> This would cause widespread sea level changes, modification of agricultural zones, and probably climate change of unknown proportions. Previously, scientists believed that the main cause of climate change was carbon dioxide emissions, but now it is known that the other trace gases play important roles. Current models indicate that warming due to trace gases could increase the potential carbon dioxide climate change by 50% to more than 100% over the next century.<sup>30</sup>

Depletion of the ozone layer in the stratosphere has been noted in the last decade. The pollutant ozone is found in the troposphere; it is injurious to health at these lower levels. However, ozone naturally occurs in the stratosphere in concentrations of a few parts per million. This small amount absorbs a significant amount of solar ultraviolet radiation and therefore protects the biosphere from harmful effects. Several chemical compounds from industrial or agricultural processes such as carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons, can affect the ozone layer with negative environmental and climatic consequences.<sup>31</sup> The United States Environmental Protection Agency (EPA) has predicted that, if chemical emissions are not curbed, increased ultraviolet radiation from ozone depletion is likely to cause 40 million skin cancers in the United States, with 800,000 of them fatal, over the next two centuries. The

EPA study assumed a 2.5% increase in CFC production per year.<sup>32</sup> Recently, a springtime decrease in the ozone layer over Antarctica has been noted. From 1979 to 1985, there has been a dramatic thinning of the ozone layer in September and October, with a recovery in November. It is unknown whether this 'hole' is a leading indicator of a catastrophic global ozone depletion. There is not enough data to determine with certainty the causes of the seasonal ozone changes over Antarctica. There are hypotheses based on CFC emission, and others based on natural mechanisms.<sup>33</sup>

The earth is an open system with respect to energy, but it is closed with respect to chemical elements. These elements move through the ocean atmosphere, and lithosphere over varying periods of time. Three of the most important cycles for life are those of carbon, nitrogen, and sulfur. Only recently has human production and transfer of these elements become great enough to affect these cycles.

The carbon cycle is critical to life because solar energy becomes available for humans through plants converting atmospheric carbon dioxide to sugar during photosynthesis. The earth's crust is the biggest reservoir of carbon, with the ocean second. Human economic activity is now transferring terrestrial stores of carbon into the atmosphere. Fossil fuel combustion adds approximately 5 billion tons of carbon annually, while burning of biomass fuels and burning for shifting cultivation and grasslands management adds another 3 billion tons annually.<sup>34</sup> Previously, it was thought that the ocean would remove the carbon dioxide in the atmosphere due to human activity. However, there has been a net accumulation as atmospheric carbon dioxide has risen from 270 to 290 ppm in 1850 to 340 in 1980.<sup>35</sup> Increased carbon in the atmosphere is one of the primary factors in the global warming of climate. Humans are altering the global carbon cycle on a large scale, but there is much uncertainty as to the ultimate effects due to inadequate knowledge of atmospheric processes and ocean mixing and circulation.

Nitrogen is a basic component of all amino acids, the building blocks of protein. Biological nitrogen fixation was once the only significant pathway for transferring biologically unavailable atmospheric nitrogen to a biologically available form. Usable nitrogen is scarce in surface waters and soils; thus it is a primary limiting factor in ecosystems. Terrestrial microorganisms supply 100 million to 175 million tons of nitrogen to the soil annually. Now this source has been augmented by chemical synthesis of nitrogenous fertilizer at rate of 60 million tons of nitrogen annually.<sup>36</sup> Nitrogen fertilizer production and use is humanity's biggest interference in the nitrogen cycle. Although nitrogen is necessary for life, nitrates from fertilizer application may pollute ground and surface water. Anthropogenic combustion of fossil fuels and biomass releases nitrogen oxides into the atmosphere. Human interference in the nitrogen cycle is one of the important causes of acid rain, ozone depletion, and global climate warming.

Sulfur, unlike nitrogen or carbon, maintains no major reservoir in the atmosphere. The greatest human influence on the sulfur cycle is the release of sulfur to the atmosphere through the combustion of oil and coal, and smelting of sulfur bearing metallic ores.<sup>37</sup> Important natural emissions of sulfur to the atmosphere are sea spray, volcanoes, and biogenic emissions from the ocean and continents. The annual worldwide human contribution of sulfur to the atmosphere is from 82 to 112 million tons, while natural fluxes are from 115 to 265 million tons per year.<sup>38</sup> Sulfur does not have a long time of residence in the atmosphere, so remote locations have not shown increased worldwide atmospheric concentrations as is the case with carbon. However, present anthropogenic additions to the sulfur cycle are primary causes of acid precipitation which is harmful to ecosystems and human health. As with the other geochemical cycles, humanity is affecting the sulfur cycle with little knowledge of the ultimate results.

The oceans are directly or indirectly used as sinks for virtually all pollutants. The main ocean pollutants are organic wastes, oil, heavy metals, halogenated hydrocarbons, and solid wastes. Organic wastes come primarily from sewage sludge from treatment



plants or raw sewage dumped at sea. Five million tons of petroleum hydrocarbons from land and sea operations reach the world's seas and oceans annually.<sup>39</sup> Petroleum hydrocarbons are toxic to human beings, and a wide variety of marine plants and animals, particularly shellfish and finfish in the larval stage. However, the petroleum hydrocarbons are subject to bacterial degradation so they do not accumulate in the food chain. Unlike petroleum hydrocarbons, heavy metals such as cadmium and mercury, and halogenated hydrocarbons such as DDT, dieldrin, and PCBs, are not subject to bacterial degradation; these long-lived toxic compounds accumulate in the food chain and can disperse over wide areas. Although much of these come from river runoff and sewage sludge, atmospheric deposition is an important pathway for metals and synthetic chemicals.<sup>40</sup>

The worst ocean pollution is localized in coastal areas and land locked seas. Although these areas represent only about 10% of the total ocean area, they yield over 90% of the world's marine fish catch. Coastal wetlands are among the most productive ecosystems on earth; mangrove forests, salt marshes, and estuaries produce larger amounts of organic material than most terrestrial ecosystems of similar size including cultivated land. Approximately two thirds of the major U. S. commercial fisheries depend upon estuaries and salt marshes as nursery and spawning grounds.<sup>41</sup> In addition to their critical role in sustaining commercial fishing, coastal wetlands also provide flood control protection and act as natural filters for some pollutants. The estuarine environment is the part of the ocean most threatened by discharges of sewage, petroleum hydrocarbons, synthetic chemicals, metals, radioactive discharges, waste heat, urban wastes, and dredging spoils.<sup>42</sup> These inshore resources could be seriously damaged long before pollution impacts are detected in offshore waters.

Groundwater is an important resource that is threatened by water mining and pollution. Water mining occurs when the drawing down of the aquifer is greater than the rate of replenishment. This can result in losses of useful agricultural land, subsidence,

and saltwater intrusion in coastal areas. Groundwater pollution is a serious threat in the United States because one half of the nation depends on groundwater for potable water, and it is more serious than river pollution because it is almost impossible to clean up.<sup>43</sup> Sources of groundwater pollution include hazardous waste sites, landfills, underground and surface mines, oil and gas exploration, saltwater intrusion, septic tanks, leaking underground sewer lines, underground petroleum storage tanks, agricultural runoff containing pesticides and fertilizer, runoff from city streets and highways that includes de-icing salts, underground and surface mines, and the municipal and industrial pollutants affecting surface waters that connect to aquifers. Toxics are a particularly serious threat to groundwater supplies; the United States government estimates that roughly 1 to 2% of groundwater in the nation is at least moderately polluted by point sources alone such as leaking landfills and hazardous waste dumps.<sup>44</sup>

Now we turn to biological diversity. There has been concern over the rate of species extinctions caused by humans in recent years. Between 1600 and 1900, roughly one species was extinguished every four years, and between 1900 and 1980 about one species every year.<sup>45</sup> Although tropical moist forests account for only 7% of the earth's land surface, they contain 40 to 50% of the estimated 5 to 10 million species on earth.<sup>46</sup> Hence deforestation of these areas poses the greatest worldwide threat to biological diversity.<sup>47</sup> Due to loss of habitat through human activities, it is estimated that 20% of these species will be extinct by the year 2000, and in 50 years over half will be gone if current rates of destruction continue.<sup>48</sup> Loss of biotic diversity would eliminate a major potential source of pharmaceutical products, industrial materials, and natural genotypes that could be combined with agricultural crops to impart resistance to insects, disease, etc. Many of these species could have economic value, but even species that would never be used as a natural resource may play critical roles in ecosystem balance. Examples of environmental services provided by tropical forests are watershed functions, soil stabilization, and climate regulation.

Marketable and nonmarketable natural resources are necessary to present and future economic systems. This brief review of human use of natural resources in the 1980's demonstrates that concern with accounting for them in measures of income and wealth is well founded.

- <sup>4</sup>International Institute for Environment and Development & The World Resources Institute, World Resources 1987 (New York: Basic Books, Inc., 1987), pp. 306-307.
- <sup>5</sup>The Worldwatch Institute, State of the World 1987 (New York: W. W. Norton & Company, 1987), p. 5.
- <sup>6</sup>Food and Agriculture Organization of the United Nations, 1984 FAO Production Yearbook vol. 38 (Rome: FAO, 1985), p. 99. Cereals include wheat, rice, maize, and barley.
- <sup>7</sup>The World Commission on Environment and Development, Our Common Future (New York: Oxford University Press, 1987), p. 128.
- <sup>8</sup>Report by United Nations Environment Programme, The World Environment 1972-1982 (Dublin: Tycooly International Publishing Limited, 1982), p. 277.
- <sup>9</sup>World Resources 1987, p. 48. The soil loss tolerance level is the maximum rate of annual soil loss that will still support crop productivity; it averages about 10.2 metric tons of soil lost per hectare per year.
- <sup>10</sup>State of the World 1987, p. 137.
- <sup>11</sup>Food and Agriculture Organization of the United Nations, Yearbook of Forest Products 1972-1983 (Rome: FAO, 1985), p. 64-65. Roundwood is the broadest class of wood products. It encompasses sawlogs and veneer logs, pitprops, pulpwood, and other industrial volumes such as wood chips.
- <sup>12</sup>The World Environment 1972-1982, p. 261.
- <sup>13</sup>Malcolm Hadley and Jean-Paul Lamy, "Tropical forest ecosystems: identifying differences, seeing similarities," Nature and Resources (1983), pp. 16-17.
- <sup>14</sup>*Ibid.*, p. 10.
- <sup>15</sup>Food and Agriculture Organization of the United Nations, Yearbook of Fishery Statistics, volumes 45 (1977) and 57 (1983) (Rome: FAO, 1984), p. 2 in Volume 45 and p. 18 in Volume 57.
- <sup>16</sup>The Worldwatch Institute, State of the World 1985 (New York: W. W. Norton & Company, 1985), pp. 76-79.
- <sup>17</sup>World Resources 1987, p. 147.
- <sup>18</sup>Paul Ehrlich, Anne Ehrlich, and John Holdren, Ecoscience: Population, Resources, Environment (San Francisco: W. H. Freeman and Company, 1977), p. 544.
- <sup>19</sup>The Conservation Foundation, State of the Environment: An Assessment at Mid-Decade (Harrisonburg, Virginia: R. R. Donnelley & Sons Company, 1984), p. 94.
- <sup>20</sup>F. H. Bormann, "Air Pollution and Forests: An Ecosystem Perspective," Bioscience, Vol. 35, No. 7, (July/August, 1985), p. 436.
- <sup>21</sup>World Resources 1987, p. 154.
- <sup>22</sup>James Galloway, et al, "Trace Metals in Atmospheric Deposition: A Review and Assessment," Atmospheric Environment, Vol. 16, No. 7, (1982), p. 1687.
- <sup>23</sup>Arthur H. Johnson, "Acid Deposition: Trends, Relationships, and Effects," Environment, Vol. 28, No. 4, (May, 1986), p. 6.
- <sup>24</sup>State of the World 1985, p. 101.
- <sup>25</sup>The World Environment 1972-1982, p. 142-44.
- <sup>26</sup>The World Resources Institute and the International Institute for Environment and Development, World Resources 1986 (New York: Basic Books, Inc., 1986), p. 204.

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- 27F. H. Bormann, "Air Pollution and Forests: An Ecosystem Perspective", p. 434.  
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 30Frederick Luther, "Projecting the Climatic Effects of Increasing Carbon Dioxide: Volume Summary," in Projecting the Climatic Effects of Increasing Carbon Dioxide, editors Michael MacCracken and Frederick Luther. (Washington, D. C.: United States Department of Energy, 1985), p. 271.  
 31Guy Brasseur, "The Endangered Ozone Layer," Environment, Vol. 29, No. 1, (January/February, 1987), p. 9.  
 32Barry Meier and Robert E. Taylor, "Bid for Global Chemical Emissions Limit Expected at 40-Nation Meeting on Ozone," Wall Street Journal, Thursday, November 6, 1986.  
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 36ibid, p. 129.  
 37State of the World 1987, p. 159.  
 38Carbon Nitrogen Sulfur Human Interference in Grand Biospheric Cycles, p. 271.  
 39R. B. Clark, Marine Pollution (Oxford: Clarendon Press, 1986), p. 31.  
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 42The World Environment 1972-1982, p. 95.  
 43Marjorie Sun, "Ground Water Ills: Many Diagnoses, Few Remedies," Science, Vol. 232, (June 20, 1986), p. 1490.  
 44ibid, p. 1490.  
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## **Chapter 3: Framework for Analysis of Production, Income, and Wealth**

### **1. Introduction**

The purpose of this chapter is to provide a general framework for the analysis of production functions with natural capital service flows, Hicksian income and wealth, and income measurement in the case of natural capital service flows. The structure of this chapter is as follows: In Section 2, we present an aggregate production function which provides a frame of reference for understanding the role of natural capital and waste in production. We provide a brief historical treatment of the economic theory of value in Section 3, and we discuss Hicksian income in Section 4. In Section 5, we consider problems associated with measurement of natural capital and its corresponding service flows.

### **2. Aggregate Production Function**

The aggregate production functions for output and waste are:

$$(1) \quad y = f(m, r, u, z)$$

$$(2) \quad w = g(m, r, u, z)$$

where:

$y$ - vector of goods and services of economic value produced in year  $t$ . This includes final consumer and government goods ( $C$  and  $G$ ) as well as intermediate goods and capital ( $I$ ). If prices are given, then we can aggregate the total vector of goods and services to measure  $GNP = C + G + I + (Ex - Im)$ .

$w$ - vector of non-economic waste generated in year  $t$ .

$z$ - vector of intermediate goods from year  $t-1$  used in production in year  $t$ .

- m - vector of service flows from human-made capital and labor. These flows originate from the stock of capital and labor agents, according to the production functions noted below.
- r - vector of service flows from natural capital. These flows originate from the stock of marketable and non-marketable natural capital agents, explained below.
- u - vector of raw material flows. These material inputs are unprocessed, in situ resources. They originate from the stock of capital and labor agents, according to the production functions noted below. Processed resources are included as intermediate goods.

Service flow production functions can be specified as follows,

$$(3) \quad m = m(M, R, w_{-1})$$

$$(4) \quad r = r(M, R, w_{-1})$$

$$(5) \quad u = u(M, R, w_{-1})$$

where:

- M - vector representing the stock of human-made capital and labor.
- R - vector representing the stock of natural capital, including both marketable and non-marketable natural capital.
- $w_{-1}$  vector of non-economic waste generated in year  $t-1$ .

The service flow production functions represent the fact that capital (reproducible, labor, and natural) acts as an agent in the production process by yielding a service flow. Both human and natural capital are in each service flow function, indicating that the ability of any one type of capital to yield a flow of services depends on the service flows of other capital types. For example, the ability of human capital to generate services depends not only on the physical capital with which human capital is combined, but also on the flow of water and oxygen necessary to support life. The latter derive from natural capital. The

water and oxygen service flows from natural capital in turn depend on the stock of trees, which provide the service of the oxygen-carbon dioxide cycle. Both human and natural capital are also in the raw materials flow function, indicating that the ability of natural capital to yield a flow of raw materials depends on the services of reproducible and labor capital. For example, the flow of coal is greater with modern machinery than with the early digging equipment.

The natural capital stock is completely general. It includes marketed capital, such as land. It also includes non-marketed capital, such as the stock of air. (The necessary and sufficient conditions for marketability are: usefulness, scarcity, and capturability.)

In order to see the factors which may change our two dependent variables,  $y$  and  $w$ , we can totally differentiate equations (1) and (2)

$$(6) \quad dy = f_m dm + f_r dr + f_u du + f_z dz$$

$$(7) \quad dw = g_m dm + g_r dr + g_u du + g_z dz$$

Equations (6) and (7) reveal the marginal product of each input in producing economic output and waste respectively. For example,  $f_m$  is the marginal product of the service flow from reproducible capital and labor in producing additional economic output.

Changes in  $m$ ,  $r$ ,  $u$ , and  $z$  will cause changes in  $y$ . Equations (6) and (7) do not directly reveal the role of  $M$ ,  $R$ , and  $w_{-1}$  on output and waste because these inputs act through the service and raw material flows  $m$ ,  $r$ , and  $u$ . Hence we will differentiate equations (3) - (5) in order to show these indirect effects:

$$(8) \quad dm = \frac{\partial m}{\partial M} dM + \frac{\partial m}{\partial R} dR + \frac{\partial m}{\partial w_{-1}} dw_{-1}$$



$$(9) \quad dr = \frac{\partial r}{\partial M} dM + \frac{\partial r}{\partial R} dR + \frac{\partial r}{\partial w_1} dw_1$$

$$(10) \quad du = \frac{\partial u}{\partial M} dM + \frac{\partial u}{\partial R} dR + \frac{\partial u}{\partial w_1} dw_1$$

Changes in  $M$ ,  $R$ , or  $w_1$  will change  $m$ ,  $r$ , or  $u$  directly and thus change  $y$  and  $w$  indirectly. The above three equations show the role of natural capital in production. Natural capital may yield a flow of raw materials in production. For example, the stock of oil in the ground is automatically depleted as it provides a flow of raw materials. This case corresponds to a nonzero  $\partial u / \partial R$  in equation (10) above. However, the same natural capital may also yield a flow of services independently of its use as a raw material. For example, oil remaining in underground reservoirs in coastal areas reduces subsidence of overlaying land. The oil capital yields a service without being depreciated in the process. This case corresponds to  $\partial r / \partial R$  greater than zero in equation (9). Of course, natural capital can yield raw materials and services at the same time also. For example, the stock of fish yields both raw materials and a psychic flow of pleasure in recreational fishing.

Since we are particularly interested in the effect of  $w_1$  on economic output, we will differentiate equation (1) with respect to  $w_1$ :

$$(11) \quad \frac{dy}{dw_1} = f_m \frac{dm}{dw_1} + f_r \frac{dr}{dw_1} + f_u \frac{du}{dw_1} + f_z \frac{dz}{dw_1}$$

The variable  $w_1$  may increase or reduce service flows of natural and human-made capital,  $m$ . For example, if  $dm/dw_1$  is negative, then waste reduces the service flows of natural capital, and thus reduces  $y$  when  $f_r$  is positive, ceteris paribus.

The above equations do not show that  $w_1$  may affect  $y$  indirectly by increasing or reducing the level of the capital stock itself. In order to see the indirect effects of  $w_1$  on economic output, we can divide equations (8) - (10) by  $dw_1$ :

$$(12) \quad \frac{dm}{dw_1} = \frac{\partial m}{\partial M} \frac{dM}{dw_1} + \frac{\partial m}{\partial R} \frac{dR}{dw_1} + \frac{\partial m}{\partial w_1}$$

$$(13) \quad \frac{dr}{dw_1} = \frac{\partial r}{\partial M} \frac{dM}{dw_1} + \frac{\partial r}{\partial R} \frac{dR}{dw_1} + \frac{\partial r}{\partial w_1}$$

$$(14) \quad \frac{du}{dw_1} = \frac{\partial u}{\partial M} \frac{dM}{dw_1} + \frac{\partial u}{\partial R} \frac{dR}{dw_1} + \frac{\partial u}{\partial w_1}$$

Substituting (12) - (14) into (11) and combining terms:

$$(15) \quad \frac{dy}{dw_1} = (f_m \frac{\partial m}{\partial M} + f_r \frac{\partial r}{\partial M} + f_u \frac{\partial u}{\partial M}) \frac{dM}{dw_1} + (f_m \frac{\partial m}{\partial R} + f_r \frac{\partial r}{\partial R} + f_u \frac{\partial u}{\partial R}) \frac{dR}{dw_1} \\ + (f_m \frac{\partial m}{\partial w_1} + f_r \frac{\partial r}{\partial w_1} + f_u \frac{\partial u}{\partial w_1}) + f_z \frac{dz}{dw_1}$$

The first term in (15) reflects the direct effects of  $w_1$  on human-made capital stocks, and, therefore, service flows. For example,  $w_1$  may reduce the stock of reproducible capital ( $dM/dw_1$  negative), reducing the flow of services from that capital (if  $\partial m/\partial M$  is positive), thus reducing  $y$  if  $f_m$  is positive, ceteris paribus. The second term in (15) reflects the effects of  $w_1$  on  $y$  through natural capital stocks, and, therefore, service flows. The third term in (15) reflects direct effects of  $w_1$  on  $y$  through services. For example,  $w_1$  may

reduce the flow of natural services (and  $w_1$  negative) and thus reduce  $y$  if  $f_1$  is positive, ceteris paribus. The fourth term in (15) reflects the effects of  $w_1$  on  $y$  through intermediate goods. There are many possible effects of  $w_1$  on  $y$  because waste can increase or decrease capital stocks and service flows. In addition,  $w_1$  may reduce the flow or stock of one type of capital and increase the flow or stock of another type of capital.

### 3. Historical Treatment of Value

Valuation of wealth, income, and natural capital presumes a definition of value and a theory of the origins of that value. Two primary value concepts have been cited by economists: total use value and marginal use value. Use value refers to the psychic flow of utility created by a good. Economists debated whether that flow originated in the person or the good. For example, classical economists attributed use value to the labor embodied in (cost) or commanded by (demand) the good.<sup>49</sup> In any case, welfare economists have come to measure total use value by the integrated areas behind appropriate demand functions; i.e., use value has come to mean willingness to pay.

Marginal use value refers to the psychic flow created by the good on the margin. Understanding of marginal use value was slow to develop, as shown by the late resolution of the diamond-water paradox and development of the neoclassical school.<sup>50</sup> Whether the good or service is traded or not, marginal use value refers to the shadow value on the margin. Exchange value refers to what the good will return the owner on the market. Alfred Marshall recognized that both cost (supply) and demand jointly determine exchange value.<sup>51</sup> From the neoclassicals on, exchange value has been viewed as a marginal property (marginal cost and marginal utility) of the good. Later it was emphasized that for exchange value to approximate shadow value there must be ownership and the ability of the owner to capture the full shadow value.

#### 4. Hicksian Income

As noted in chapter 1, Hicksian income is considered to be the maximum value that we can consume between the beginning and end of a period without being worse off at the end than at the beginning, i.e., without changing the income potential of the capital stock, or wealth.<sup>52</sup> Hence this income is a steady state concept. Wealth generates income, a psychic flow of pleasure. Wealth is valuable according to its ability to generate this income. A true economic measure of income is the true willingness to pay to avoid loss of that psychic flow of pleasure or to attain that flow. This is ambiguous to the extent that the value of what is paid, say money, is not predetermined. The closest approximation to the true economic measure is the willingness and ability to pay given a personal distribution of money income.

This willingness to pay is better represented by the integrated area lying behind the Hicksian demand curve, rather than the Marshallian demand curve, for a particular good or service.<sup>53</sup> The Marshallian demand curve gives the quantity that a utility-maximizing consumer with a given real income level will demand at each price. However, it includes both the substitution and income effects due to price changes. Hence the psychic flow of utility which we are attempting to value is itself changing as the consumer moves along the Marshallian demand curve. Due to this income effect, the integrated area behind the Marshallian demand curve does not yield the willingness to pay to avoid loss or to attain the same psychic flow. The Hicksian compensated demand curve shows the quantity a consumer will demand at each price, assuming that income is adjusted so that the person obtains the same utility. Due to the elimination of the income effect, the integrated area behind the Hicksian demand curve does yield the willingness to pay to avoid loss or to attain the same psychic flow.<sup>54</sup> Hence this area is the best economic measure of the income derived from goods and services.

The Hicksian income concept requires both a measure of income generated during a period as well as a method to account for net increases (decreases) during that period in the potential to create income. When income potential has increased, society can consume the capital which created this increase and remain as well off as at the beginning of the period. Hicksian income would then equal actual period income plus this consumable capital stock. In the presence of positive technological change, income potential from a given capital stock will increase. In this case, an additional quantity of capital may be consumed without damaging income potential.

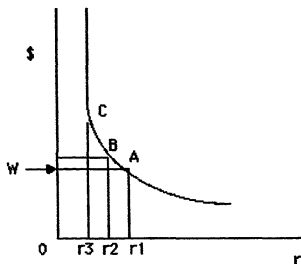
When beginning period capital stock is diminished or its income creating potential reduced, actual period income must be adjusted downward to account for the reduced income potential. This adjustment should be the lesser of the benefits lost or the cost of replacing the capital necessary to preserve the income potential. When markets are perfect, marginal capital values equal discounted incomes and, on the margin, equal the cost of replacing the capital. However, when markets are imperfect, marginal capital values may not fully equal discounted incomes, as in the case of positive externalities; or, on the margin, capital value may not equal replacement cost, as in the case of monopoly.

The income adjustments necessary for Hicksian income are especially acute in the case of increases (decreases) in environmental capital. Market valuation of this capital is likely to be very imperfect. Its income creating potential may differ greatly from replacement cost. However, in principle, income adjustments are just as important as in the case of traditional, marketed, human-made capital for purposes of measuring Hicksian income.

A special case of income adjustments necessary for Hicksian income is the loss of essential, non-abundant, natural capital. We define essential natural capital as follows: (1) The natural capital must be unique in its ability to render necessary services to humans; i.e., there can be no substitution of other types of capital in production or

consumption for provision of the necessary service. (2) The necessary services rendered by this natural capital are unique; i.e., there can be no substitution of other services in production or consumption for the services of the particular natural capital. If the above conditions hold, then the capital consumption allowance, or value of the lost income flows from this particular natural capital, is infinite.

Figure 3-1: Hicksian Demand Curve for Essential Natural Capital Service

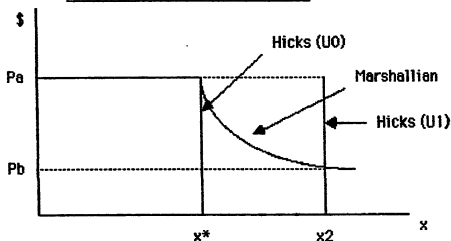


We can use the Hicksian demand curve to demonstrate that the value of an essential natural service fits our true economic measure of income.<sup>55</sup> In Figure 3-1 above, the horizontal axis measures the amount of an environmental service,  $r$ , and the vertical axis measures money. The consumer is initially at point A. If, in the limit, the environmental service is essential, then the consumer cannot be compensated for the total loss of the service; the Hicksian demand curve becomes vertical at point C as the substitution effect reaches zero. C units of the environmental service are necessary for survival. Hence the total integrated area behind the Hicksian demand curve at point A would be infinite. The Hicksian income measure indicates that the service has infinite value. There is no finite capital consumption allowance which would equal the value of

the lost environmental services. Note that the marginal loss of income from A to B, represented by area W, is finite, while the marginal loss of income from C to a point just to the left of C is infinite. Point C would correspond to a threshold level of natural capital services which are necessary for survival of an economic system.

The Hicksian demand curve can be used to value the full range of natural services from essential ones to those with perfect substitutes. Figure 3-2 below shows the Hicksian and Marshallian demand curves for a natural capital service with perfect substitutes. The derivation of these demand curves from indifference curves is presented in the appendix to this chapter. We will only consider the value of complete loss of  $x$  using Hicksian demand curve  $U_1$  here. If we start with  $x_2$  units, then the value of the total loss of this service is equal to the finite area behind the Hicksian demand curve  $U_1$ . This area is equal to  $x_2(P_A - P_B)$ . The Hicksian method for valuing changes in service flows is the same whether the good is essential or has perfect substitutes.

**Figure 3-2: Hicksian Demand Curves for Natural Capital Service with Perfect Substitutes**



### 5. Problems Associated with Measuring Natural Capital and its Income by Total Use and Marginal Use Values

Whereas income may best be measured by willingness to pay, full demand functions are difficult to obtain for many goods and services. Natural capital provides service flows and raw materials which may enter directly into consumer utility, such as aesthetic pleasure or recreational enjoyment. In this case, the good or service is desired by consumers as an end in itself. Hence the willingness to pay could be measured directly if the service is fully marketed. For the many environmental service flows which are not marketed, willingness to pay could be measured indirectly through pseudo-market experiments.

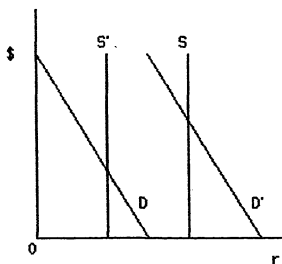
One method of indirectly determining non-market environmental values is contingent valuation in which individuals are asked in survey or experimental settings to reveal their valuations of changes in unpriced goods.<sup>56</sup> Contingent markets are used to define the good, the initial level and menu of level changes for the good, institutional structure of the market, and the method of payment. An attempt is made to provide the consumer with a well defined market in which to reveal valuations contingent on the occurrence of that particular situation.<sup>57</sup> Such studies are time consuming and expensive to implement. The requirements for determining use value are quite demanding for unmarketed environmental services which directly enter consumer utility functions.

Natural capital also provides service flows and raw materials which enter production functions for final goods and services. In this case, the consumer does not demand the natural service as an end in itself, but as a means to the production of final goods. Hence the willingness to pay for these natural services could be measured indirectly by the producing firm's input demand, the marginal revenue product of the service.<sup>58</sup> This procedure of valuation requires that final goods production functions



are known. There is a demand for both the direct and indirect services of natural capital to consumers, although it may be very difficult to estimate the demand curves and corresponding willingness to pay. The demand for service flow  $r$  is shown below.

Figure 3-3: Supply and Demand of Natural Service Flow

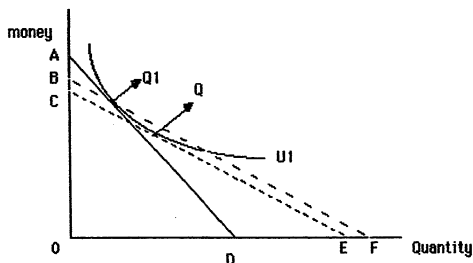


While changes in psychic income flows should be measured as changes in total use value, information requirements are too demanding. The practical alternative has been to measure marginal use value, and to measure that by market prices. All natural capital service flows have shadow values, perhaps zero, depending on the derived demand and supply of those flows. This is true whether or not they have exchange value; i.e., market prices. Some service flows may not be fully capturable (or the cost of capture exceeds anticipated revenues) by private ownership, so their shadow values are not properly reflected in market prices. In general, when property rights are not fully defined, shadow values and prices may be considerably different and even move in opposite directions. In these cases, marginal use values are poorly represented by exchange value.

Total use value and exchange value, defined as market price times quantity, may not move together even when property rights are fully established. This can be seen in Figure 3-3 as supply shifts from  $S$  to  $S'$  with demand constant at  $D$ . Total use value is diminishing yet exchange value is increasing. This fact was noted by Lauderdale, who observed that we may not be richer when a previously free good becomes scarce.<sup>59</sup> However, the two may move in the same direction as demand shifts from  $D$  to  $D'$  with supply constant at  $S$  in Figure 3-3. In this case, we are richer in the sense of having higher psychic income as the good becomes scarce; i.e., obtains a shadow value.

Economists use price and quantity indices to separate price from quantity effects in measuring welfare changes. We will briefly consider how price and quantity indices would allow for the supply and demand shifts in Figure 3-3. First, consider a 'true' price index which is derived from full knowledge of an individual's indifference map.<sup>60</sup> This true price index measures the change in the minimum cost of achieving a given utility level when prices change and all other factors including tastes are constant. A true price index will equal the ratio of the money expenditure needed to achieve the given utility level at the changed prices divided by the money expenditure needed to achieve the same utility level at the initial prices. We can show the true price index and a measurable proxy using Figure 3-4 below.

Figure 3-4: True Price Index and Laspeyres Price Index



Assume the consumer is initially at the point of tangency of indifference curve  $U_1$  and budget line  $AD$  corresponding to quantity  $Q_1$  consumed at price  $P_1$ . The money income in this initial situation is  $AO$ . Then prices change to  $P_2$  and budget line  $CE$ . The point of tangency between  $U_1$  and  $CE$  is the equilibrium quantity ( $Q$ ) which will make the consumer as well off after the price change as before. The money income necessary to achieve  $U_1$  at  $P_2$  prices is  $CO$ . The true price index is equal to:

$$(16) \quad \frac{CO}{AO} = \frac{P_2 \cdot Q}{P_1 \cdot Q_1}$$

The true price index cannot be measured because  $Q$  is unobservable. However, we can derive a measurable bound for the true price index. If the consumer had the money income  $BO$  needed to buy  $Q_1$  at price  $P_2$ , the consumer would choose another quantity  $Q_2$  on a higher indifference curve (assuming convexity of indifference curves). Thus we know that money income  $BO$  is greater than the  $CO$ , the income necessary for the consumer to adjust to  $P_2$  prices at the initial level of utility. An upper bound for the true price index can then be derived as follows:

$$(17) \quad \frac{CO}{AO} < \frac{BO}{AO} = \frac{P_2 \cdot Q_1}{P_1 \cdot Q_1} = \text{Laspeyres price index}$$

The Laspeyres price index is an upper bound of the true price index, measured for one particular initial utility level. A true price index can also be defined relative to the utility level reached after a price change. It can then be shown that the Paasche price index is an upper bound for that true price index.<sup>61</sup> However, we will just use the Laspeyres price index as a representative example in showing how price and quantity indices deal with the supply and demand shifts depicted in Figure 3-3.

For every price index, there is a corresponding quantity index.<sup>62</sup> The traditional real GNP measure is a quantity index derived from the Laspeyres price index. Since the Laspeyres price index is an upper bound of the true price index, real GNP calculated using the Laspeyres price index is a lower bound of the true change in real income. Real GNP is our measure of real income using base period prices and current quantities; changes in real GNP are measurable proxies of changes in total use value.<sup>63</sup>

Now we can determine how real GNP deals with the demand and supply shifts mentioned in Figure 3-3. First, consider the case of a supply decrease with no change in demand. Marginal shadow value increases, but total use value decreases. If the good was in existence in the initial period and had a positive price, then the price increase would be deflated to the initial period prices. Hence a real income measure would indeed show a decrease despite the price rise. The point is that, if environmental goods can be valued accurately, real income measures can be adjusted so that they do not indicate a gain in economic welfare merely due to a price rise. This treatment is just a specific case of the purpose of all real income measures; the principal reason for such measures is to avoid considering a nation as better off when quantities diminish but

prices rise. Real GNP moves in the same direction as total use value when supply shifts; hence it is an adequate measure of changes in economic welfare in this case.

Demand may increase for an environmental good over time due to the discovery of a new use or reduction in available substitutes. This will cause changes in marginal shadow values which move in the same direction as total use value in the case of a demand increase. However, real GNP will not increase due to demand changes because marginal shadow values are assumed to be the same as in the base period. Changes in unobservable tastes are ruled out in quantitatively comparing economic welfare over time. If the assumption of constant tastes is not held, then the question whether an individual or society is better off in two different situations has no meaning.<sup>64</sup> Since price indices are based on the assumption of constant tastes, price changes are interpreted as absolute inflationary or deflationary (rather than changes in relative values of one good versus others) and netted out in the calculation of real GNP. Thus real GNP may not move in the same direction as changes in total use value for demand changes. The only feasible method of dealing with the problem of demand changes is to revise the weights (and thus the real GNP series) periodically over time.<sup>65</sup> Note that there is no other real income measure which calculates changes in total use value accurately for demand changes. There is no satisfactory way of dealing with demand changes in aggregated measures of real income.<sup>66</sup>

The above discussion of price indices and supply and demand shifts has assumed that property rights are fully established; hence the problem is whether accurate exchange values (market prices times quantities where the prices are equal to the marginal shadow values) will form adequate measures of changes in total use value. A separate problem from indices as accurate measures of changes in total use value is the fact that the shadow values of many environmental services are not properly reflected in market prices. The best approach is to attempt to derive the most accurate environmental 'prices' before creating price and quantity indices for all goods. None of

the adjustments in indices will be of help if the 'base period prices' are known to be wrong in the sense that they do not represent consumers informed preferences under a system of fully defined property rights.

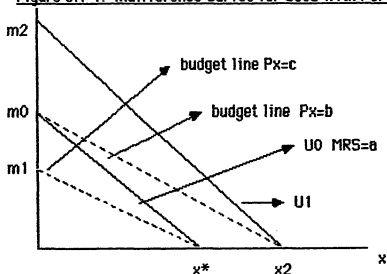
Since wealth is simply discounted income flows, problems regarding its measurement originate in income measurement problems plus the discounting problem itself.

## 6. Summary

This chapter provides a general frame of reference for basic concepts in this dissertation. These basic concepts are: the role of natural capital and waste in production, Hicksian income, and income measurement using total use value, marginal use value, and exchange value. The present economic accounts and all of the proposed environmental accounts can be considered within the general framework of this chapter.

Appendix: The Economic Value of a Good with Perfect Substitutes

Figure 3A-1: Indifference Curves for Good with Perfect Sub.

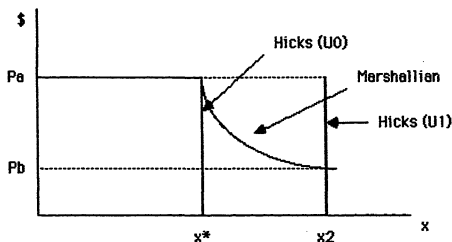


Consider the linear indifference curve  $U_0$  with  $MRS=a$ .

- (1) If the price  $c$  is less than  $a$ , then the consumer moves to a higher indifference curve and purchases some  $x$  which is greater than  $x^*$ . For example, if the price is  $b$ , the consumer will move to  $U_1$  and spend all money on  $x_2$ . There is an income effect for this price change.
- (2) If the price  $= a$ , then the consumer will purchase between  $0$  and  $x^*$  because the price line coincides with  $U_0$ . There is no income effect here.
- (3) If the price is greater than  $a$ , then the consumer will not purchase any  $x$ . There is no income effect here.

These changes allow us to derive the Marshallian and Hicksian demand curves for this good with perfect substitutes.

Figure 3A-2: Demand Curves and Consumer Surplus



The Marshallian demand curve in Figure 3A-2 can be derived from the above price changes. Above  $a$ , there is no demand; at  $a$ , the demand is infinitely elastic from 0 to  $x^*$ . For consumption greater than  $x^*$ , the demand has unitary elasticity because all revenues are spent on  $x$  for every lower price.

The Hicksian compensated demand curve which takes  $U_0$  as the point of reference will be the same as the Marshallian demand curve for prices which are greater than or equal to  $a$  because of the absence of income effects for those price changes. However, for prices below  $a$ , the Hicksian demand curve ( $U_0$ ) will be a vertical line at  $x^*$  because the consumer loses the extra income from the price fall. Hence the price line is shifted in (for example, from  $b$  to  $a$ ), and the utility maximizing position is always  $x^*$  for prices below  $a$ .

The Hicksian compensated demand curve which takes  $U_1$  as the point of reference will be zero for prices above  $a$ , and infinitely elastic for  $p=a$  between 0 and  $x_2$ . It will be a vertical line at  $x_2$  for prices below  $a$  because the consumer loses the extra income from the price fall. The reasoning is the same as that stated earlier for the Hicksian demand curve which uses  $U_0$  as the point of reference.



We can now calculate the willingness to pay for  $x_2$  in terms of the compensating variation (CV) and equivalent variation (EV).

Original state: ( $P_x=b$ ,  $U_1$ ,  $x_2$ ,  $m_0$ )

CV is what you have to be paid to accept complete loss of  $x_2$ . This amount is equal to the dollars which returns consumer to  $U_1$  after the price change, or  $(m_2 - m_0)$  in Figure 3A-1. Note that  $m_2 = P_a(x_2)$  and  $m_0 = P_b(x_2)$ .

Thus  $CV = (m_2 - m_0) = x_2(P_a - P_b)$ .

EV is the dollars taken away which is equivalent to loss of opportunity to buy  $x_2$ , or how much the consumer would pay to have access to  $x_2$  at  $P_x=b$  rather than  $P_x=\text{infinity}$ . This is equal to  $(m_0 - m_1)$  in Figure 3A-1. Note that  $m_0 = P_a(x^*)$  and  $m_1 = P_b(x^*)$ . Thus  $EV = (m_0 - m_1) = x^*(P_a - P_b)$ . CV is greater than EV.

<sup>49</sup>David Ricardo considered exchange value to be equal to the labor embodied in the good, whereas Thomas Malthus considered exchange value to be equal to the quantity of labor which the good enables the owner to command. See the following references:

Thomas R. Malthus, Principles of Political Economy. 2nd edition. (New York: Augustus M. Kelley, 1964), p. 60.

David Ricardo, The Works and Correspondence of David Ricardo Edited by Piero Sraffa with collaboration of M. H. Dobb, volume 1: On the Principles of Political Economy and Taxation (Cambridge: the University Press for the Royal Economic Society, 1951), p. 17.

<sup>50</sup>W. Stanley Jevons, The Theory of Political Economy. 5th edition. (New York: Kelly & Millman, Inc., 1957), p. 79. Jevons reinterpreted Adam Smith's famous diamonds and water paradox in terms of total and marginal utility rather than exchange and use value.

<sup>51</sup>Alfred Marshall, Principles of Economics. 8th edition. (London: Macmillan and Co., Limited, 1952), pp. 290-291.

<sup>52</sup>J. R. Hicks, Value and Capital. 2nd edition. (Oxford: The Clarendon Press, 1965), p. 172.

<sup>53</sup>J. R. Hicks, "The Rehabilitation of Consumers' Surplus," The Review of Economic Studies, Vol. 8, No. 2, (February, 1941), pp. 108-116.

<sup>54</sup>The reader may question whether we are valuing income by using the compensating variation or equivalent variation. We are interpreting income in the sense of the compensating variation; thus the same psychic flow in the above sentences refers to the original psychic flow of income from the natural capital. The value of this service is what one would have to pay the consumer after a price or quantity change to make the person as well off in the new state as he or she was in the original state. The use of the initial level of utility as a reference point corresponds to Hicks' definition of income. The use of compensating variation implies that the value of a loss of natural services be measured by the minimum sums required to compensate people for those amenities, while the value of a gain in natural services be measured by the maximum sum the beneficiaries are able and willing to pay for it. In particular, for losses of irreplaceable environmental assets, the equivalent variation measure would not appear to be relevant because society cannot survive at the state of utility after the change in quantity or price. See figure 3-1 and its explanation in this chapter. For a discussion of the use of compensating and equivalent variation in environmental valuation, see E. J. Mishan, Economic Efficiency and Social Welfare (London: George Allen & Unwin Ltd., 1981), pp. 165-173.

<sup>55</sup>J. R. Hicks, "The Four Consumer's Surpluses," The Review of Economic Studies, Vol. 11, No. 1, (Winter, 1943), p. 40. Hicks considered a commodity which is an absolute necessity, such as a certain amount of food. He showed that the Hicksian measure of value (compensating variation) of such a good would be infinite. Hicks did not consider this case to be important in practice because "no theory of economic policy will want to discuss the desirability of measures which would involve the deliberate withdrawal from production of things which are absolute necessities, or even of things which are anywhere near being absolute necessities." In our time, there is a real possibility that society will inadvertently withdraw natural production of goods which may be absolute necessities. Hence the relevance of this special case is increased.

<sup>56</sup>R. G. Cummings, D. S. Brookshire, and W. D. Schulze. Valuing Environmental Goods: An Assessment of the Contingent Valuation Method (Totowa, New Jersey: Rowman & Allanheld, 1986).

<sup>57</sup>For an example of the application of the contingent valuation method to changes in natural resource service flows, see: David S. Brookshire, Alan Randall, and John R. Stoll, "Valuing Increments and Decrements in Natural Resource Service Flows," American Journal of Agricultural Economics, Vol. 62, No. 3, (August, 1980), pp. 478-488.

<sup>58</sup>Daniel Wisecarver, "The Social Costs of Input-Market Distortions," American Economic Review, Vol. 64, No. 3, (June, 1974), p. 361.

<sup>59</sup>Lauderdale, An Inquiry into the Nature and Origin of Public Wealth and into the Means and Causes of its Increase. 2nd edition. (Edinburgh: Archibald Constable & Co., 1819), pp. 44, 57-58.

<sup>60</sup>Nissan Liviatan and Don Patinkin, "On the Economic Theory of Price Indexes," Economic Development and Cultural Change, Vol. 9, No. 3, (April, 1961), p. 504.

<sup>61</sup>R. G. D. Allen, "The Economic Theory of Index Numbers," Economica, Vol. 16, (August, 1949), pp. 197-203. Note that there is a 'true' price index for every different utility level used as a reference point; hence there are as many true price indexes as there are utility levels. Thus we cannot say that the one true price index is bounded from above and below by the Laspeyres and Paasche price indexes. This is because the Laspeyres and Paasche indexes form bounds for different true price indexes (i.e., indexes that are relative to different utility levels).

<sup>62</sup>We are not deriving the 'true' quantity index from indifference curves in this paper. A true quantity index is a measure of the magnitude of the shift from one utility level to another; it is measured by ratio of the money cost of acquiring the two different utility levels. The money cost depends on the set of prices used; only one set must be used for a calculation of successive real quantity changes. There is a true quantity index for each set of prices used. In this paper, we show the relation of the Laspeyres price index to a true price index, and then use the price index to calculate real GNP. This method is the one actually used to calculate real GNP in the economic accounts. Rather than counting physical quantities, real GNP is derived from value data (such as total value added) through deflation by appropriate price indexes. See the following article: Jack E. Triplett and Richard J. McDonald, "Assessing the Quality Error in Output Measures: The Case of Refrigerators," Review of Income and Wealth, Series 23, No. 2, (June, 1977), pp. 137-156.

<sup>63</sup>Note that real GNP is not a physical output measure such as our  $y$  vector introduced in equation 1. Although real GNP is a price-weighted welfare measure, a change in real GNP is interpreted as a change in quantity in the same direction because the weights (prices) are assumed to be the same over time.

<sup>64</sup>J. R. Hicks, "The Valuation of the Social Income," Economica, Vol. 7, No. 25, (1940), p. 107.

<sup>65</sup>There is an extensive literature on quality changes in real GNP, but quality changes are interpreted as an increase in supply of some characteristics of goods which are capable of quantitative measurement. It is not assumed that tastes changed. A quality change will lead to an upward change in real GNP because it is calculated by deflation with price indexes rather than through counting of physical goods. For example, if the quality of refrigerators increased over time, then it will be considered as a price fall. Hence the price index is lowered, and real GNP = nominal GNP/price index is

raised. For an example of the treatment of quality change in GNP accounts, see the following article: Jack E. Triplett and Richard J. McDonald, "Assessing the Quality Error in Output Measures: The Case of Refrigerators," Review of Income and Wealth, Series 23, No. 2, (June, 1977), pp. 137-156.

<sup>66</sup>There is some theoretical literature on taste changes and price indices. This requires some simple assumption concerning the utility function; one possibility is that taste change for a good is quantity-augmenting. For example, the utility function may be described as  $u = u(gq_1, q_2)$  at time  $t$  where  $g$  is the taste change parameter which varies over time. If  $g$  is greater than 1, then more utility is derived from smaller amounts of  $q_1$  over time; this is exactly parallel to labor-augmenting technical change in macroeconomic theory. However, it is very difficult to decide what value  $g$  should take, and actual taste changes may be far more complicated than such simple frameworks. Hence the theoretical work on taste changes has not been integrated into empirical price and quantity indices. They rely on the traditional theory of price and quantity indices which assumes constant tastes. For examples of a work which consider taste changes and price and quantity indices, see the following: R. G. D. Allen, Index Numbers in Theory and Practice (Chicago: Aldine Publishing Company, 1975).

## **Chapter 4: Natural Resources in the System of National Accounts**

### **1. Introduction**

This chapter will survey the treatment of marketable and non-marketable natural resources in the income accounts and balance sheets. In Section 2, we present basic concepts and definitions. We discuss the treatment of natural capital service flows in the income accounts in Section 3. We consider the treatment of natural capital stocks in the wealth accounts in Section 4.

### **2. Basic Concepts and Definitions**

There are several basic concepts underlying the national product measures: economic value, production, and final goods. The fundamental purpose of the National Income and Product Account is to measure the net production of economic output and the income and non-income charges against that output. An aggregate production measure requires a method of valuation and a boundary on the production process. The economic value in the present accounts is exchange value. The basic criterion used for distinguishing an activity as economic production is whether it is reflected in legal sales and purchase transactions of the market economy. Economic accounts are meant to analyze market transactions; only non-market production that has close parallels in market production is included as imputed transactions in the national accounts.<sup>67</sup> The economic accounts only measure the production of final goods; intermediate goods are considered to be already valued as part of the final good. A final good is one that is bought and not resold. In the GNP account, final goods are considered to be all government and household consumption expenditures, gross capital formation, and net

exports. Intermediate goods are those consumed in the process of producing goods for consumers and government.

GNP double counts in considering gross capital formation as final even though some capital is consumed in the current production of goods and services. Therefore GNP is not a measure of a sustainable flow of production. This is the reason for the measurement of NNP which is equal to GNP minus the capital consumption allowance, an estimate of the reproducible capital consumed in the current production of goods and services by the business sector.

### 3. Natural Capital Flows in the Income Accounts

GNP and NNP are not adjusted for discovery or depletion of marketable natural resources. Charges to reserves for depletion are added into business profits. "For this there is the conceptual reason that discovery of mineral resources is not counted as gross capital formation, so that allowance of depletion destroys the balance between capital formation and capital consumption."<sup>68</sup> Hence, although the present accounts include the flow of production from marketable natural capital, GNP and NNP assume that the value of marketable natural capital does not appreciate or depreciate due to ongoing production flows. The practical reason for not adding appreciation or subtracting depreciation of marketable natural resource capital from NNP is the formidable difficulty in estimating physical quantities of natural resource reserves and valuing these physical estimates. The exclusion of capital appreciation or depreciation from GNP and NNP means that these measures do not indicate the relation between the present flow of production and the stock of marketable natural capital. Neither measure will indicate whether the current flow of production is sustainable in terms of the demands placed on marketable natural capital.

The income accounts do not directly include non-marketable natural capital appreciation, depreciation, or service flows. The only way a change in these service flows could influence GNP or NNP is if their changed quantity or quality made the production of items which are included in the list of final products easier or more difficult.<sup>69</sup> The exclusion of non-marketable environmental capital and its services from GNP is primarily due to serious valuation problems.<sup>70</sup>

The exclusion of nonmarketable natural capital service flows means that unremedied degradation of such capital is not recognized as a loss of income. Expenditures to remedy environmental degradation by government or households count as new production and income rather than as a non-income charge for consumption of environmental capital. However, expenditures to remedy environmental degradation by the business sector are considered as intermediate goods in GNP.<sup>71</sup> An example of such remedial expenditures is the estimates of public and private spending for pollution abatement and control (PAC) by the Bureau of Economic Analysis.<sup>72</sup> These PAC expenditures have been published as annual series in the Survey of Current Business since 1975.

In sum, the present national income measures do not account for the appreciation or depreciation of natural capital. Neither GNP nor NNP indicate whether current production and income flows are building or destroying marketable and non-marketable natural capital. Thus they are inadequate measures of Hicksian income in the case of natural capital service flows.

#### 4. Natural Capital in the Wealth Accounts

The distinguishing characteristic of all wealth is its capacity to contribute to future income flows. Thus capital assets are generally valued in terms of their expected future net income stream discounted to the present; this is their price under ideal conditions.

The aggregate national wealth is made up of primarily tangible wealth consisting of productive marketable natural resources, structures, equipment, inventories, plus net financial claims on other countries. Marketable natural capital is included in national wealth measures as non-reproducible tangible assets.<sup>73</sup> The present national balance sheets include an aggregate value for the marketable component of natural capital.

It is important that wealth accounts be compatible with the income accounts. The United Nations has published guidelines on balance sheet accounts with this objective. Natural resources are difficult to value due to uncertainty in physical measurement and estimation of monetary worth. Hence their treatment in the income accounts is not the same as reproducible capital which is more easily measured. The concepts, definitions, and classes of reproducible capital are consistent with the corresponding flows in GNP accounts. The physical change in reproducible capital stocks shows up in the flow accounts as gross fixed capital formation, changes in inventory stocks, and normal consumption of fixed assets.<sup>74</sup> But the income accounts exclude the changes in natural resource assets; one cannot go directly from the balance sheets to the income accounts to determine the use of natural resource stocks. Instead, they are recorded in reconciliation accounts which bridge the gap between the balance sheets and the income accounts. The function of the reconciliation accounts is to portray all the differences between the opening and closing assets and liabilities on the balance sheet accounts that are not covered in the capital finance accounts and thus not in the income accounts.<sup>75</sup>

For reproducible capital, an attempt is made in the reconciliation accounts to separate revaluations due to price changes from those due to quantity changes. The reproducible capital stock accounts may change in value due to price or discount rate changes; these man-made capital gains or losses are not considered in the capital finance accounts; thus they appear in the reconciliation accounts. The classification of 'net increases in the value of tangible assets not accounted for in the capital finance



accounts' exists because changes in the stocks of marketable natural resources are excluded from the capital finance accounts.<sup>76</sup> Although revaluations due to price changes for reproducible capital are also excluded from income accounts and set in the reconciliation accounts, neither quantity nor price changes in the value of natural resources are brought into the flow accounts.

We can use a simple example to illustrate the different treatment of reproducible capital and marketable natural resources in the economic accounts. Assume that in year 1, the capital stock is \$100 and the natural resource stock is \$200. In year 2, the balance sheet items are \$250 for capital and \$300 for natural resources. The \$150 increase in the capital stock is made up of a \$20 revaluation (capital gain) and \$130 of net physical capital formation. The \$100 increase in the natural resource stock is made up of a \$25 revaluation and \$75 of net natural resource formation (new discoveries minus depletion). The capital finance accounts and thus NNP will only record the \$130 in net physical capital formation; thus one cannot tell from the income accounts what factors were responsible for the other changes in the balance sheets from year 1 to year 2.

Reconciliation accounts are needed to record the change in capital stocks due to price changes and the change in natural resource stocks due to price and quantity changes. If natural resources were treated like reproducible capital, then the \$75 of net natural resource formation would also be recorded in the income accounts; NNP would include net natural resource formation as well as net capital formation, and GNP would include gross natural resource formation as well as gross capital formation. Reconciliation accounts would only be used for price changes and other categories unrelated to the distinction between reproducible capital and natural resources.<sup>77</sup>

Thus marketable natural capital is linked only formally to the flow accounts through the reconciliation accounts. Suggestions for transferring environmental reconciliation items into the income accounts by means of capital formation for resource discovery and depletion have been opposed by the 1986 Expert Group Meeting on the

United Nations System of National Accounts. The reason is that the additions would lead to unacceptable movements of GNP over time.

Nonmarketed natural capital such as air is not included in the balance sheets or reconciliation accounts. It is recognized that in the highly industrialized countries, these formerly 'free goods' gradually become economic goods because they require investment and maintenance costs in the same way as fixed capital.<sup>78</sup> Therefore, in principle, they should be included in the non-reproducible tangible assets of the balance sheets, but the valuation problems are too difficult. Hence non-marketable natural capital stocks and service flows do not directly appear in the income accounts, balance sheets, or reconciliation accounts.

In sum, the present income and wealth measures do not adequately account for environmental factors. We have no measure of Hicksian income which considers natural capital service flows. However, the need for such a measure is critical in light of the trends in natural resource use presented in Chapter 2. At present, we do not know if economic activity is actually increasing the net total of services from man-made and natural capital, and we do not know if present income levels are sustainable. The next two chapters will examine recent accounting proposals which attempt to better represent environmental factors in measures of income and wealth.

<sup>67</sup>United States Department of Commerce, "The Conceptual Framework of National Income Statistics," Survey of Current Business, 1954 Supplement, p. 30. The main imputations of this type are for the value of food produced and consumed on farms, the rental value of owner-occupied houses, and for non-monetary income and product flows arising in connection with financial intermediaries.

<sup>68</sup>Edward F. Denison, "Report on Tripartite Discussions of National Income Measurement," in Studies in Income and Wealth Volume 10 (New York: National Bureau of Economic Research, 1947), p. 14.

<sup>69</sup>Oris Herfindahl and Allen Kneese, "Measuring Social and Economic Change: Benefits and Costs of Environmental Pollution," in The Measurement of Economic and Social Performance Milton Moss, editor. (New York: National Bureau of Economic Research, 1973), p. 447.

<sup>70</sup>*ibid.*, p. 448.

<sup>71</sup>A solution to the consideration of remedied degradation of non-marketable natural capital as income would require a functional analysis of government and household expenditures by purpose. Then expenditures designed to defend against degradation of environmental capital could be labeled intermediate rather than final. Simon Kuznets earlier advocated a similar approach to government and personal consumption expenditures. See the following: Simon Kuznets, "Discussion of the New Department of Commerce Income Series: National Income: A New Version," and Milton Gilbert, George Jaszi, Edward F. Denison, and Charles F. Schwartz, "Objectives of National Income Measurement: A Reply to Professor Kuznets," Review of Economics and Statistics, Volume 30, No. 3, (August, 1948), pp. 151-95.

<sup>72</sup>John E. Cremeans, "Conceptual and Statistical Issues in Developing Environmental Measures- Recent U.S. Experience," Review of Income and Wealth, Series 23, No. 2, (June, 1977), p. 100. Business expenditures for pollution control on current account are considered to be intermediate. Business expenditures for capital goods for abatement are counted as gross investment in the year they occur, thus adding to GNP. But the effect on GNP in the years that the capital good is in service differs from other capital goods. An ordinary capital good produces a stream of services whose dollar values enter into future GNP. The stream of services provided by abatement capital does not because it has no market value.

<sup>73</sup>Department of Economic and Social Affairs, Provisional International Guidelines on the National and Sectoral Balance-Sheet and Reconciliation Accounts of the System of National Accounts, Series M, No. 60. (New York: United Nations, 1977), p. 27-28. Non-reproducible tangible assets include land, timber tracts and forests, subsoil assets and extraction sites (energy resources), metallic mineral reserves, mines, and sites, non-metallic mineral reserves, mines and sites, fisheries, and historical monuments.

<sup>74</sup>Department of International Economic and Social Affairs, Guidelines on Statistics of Tangible Assets, Series M, No. 68. (New York: United Nations, 1979), p. 11.

<sup>75</sup>Provisional International Guidelines on the National and Sectoral Balance-Sheet and Reconciliation Accounts of the System of National Accounts, p. 55.

<sup>76</sup>*ibid.*, pp. 55-59. These changes are divided into the following categories: (1) natural growth less depletion of breeding stock, timber, fisheries, and plantations, orchards, vineyards. (2) new finds less depletion of subsoil assets. (3) losses in land and timber tracts in catastrophes and natural events.

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<sup>77</sup>ibid. p 76. The reconciliation items are: revaluations due to price changes, issue of IMF special drawing rights, adjustments in respect of unforeseen events, net changes in value of tangible assets not accounted for in the capital finance accounts (natural resources), adjustments due to changes in structure and classification, termination of purchased patents, copyrights, trade marks, etc., and statistical discrepancies and discontinuities.

<sup>78</sup>Guidelines on Statistics of Tangible Assets, p. 8.

## **Chapter 5: Review of Aggregated Environmental Accounting Frameworks**

### **1. Introduction**

In this chapter and the next, we will survey and critique proposals to modify the existing national economic accounts to better represent environmental factors and thus more accurately reflect sustainable income flows. We will review aggregated and disaggregated methods of environmental accounting in chapters 5 and 6 respectively. Aggregated methods portray the value of environmental factors using one monetary figure while disaggregated methods use a combination of monetary figures and physical environmental quality indicators. In Section 2 of this chapter, we consider an ideal conceptual NNP based on the concept of Hicksian income. In Section 3, we introduce aggregation and disaggregation as two different responses to the problem of measurement of sustainable income. In Section 4, we examine several proposals for the monetary valuation of marketable environmental capital and the inclusion of its income and depreciation in the accounts. In Section 5, we present a proposal for monetary valuation of nonmarketable environmental capital and the inclusion of its income and depreciation in the accounts. In Sections 6 and 7, we review mass-energy-balance and energy analysis accounting methods respectively. Section 8 is the chapter summary.

### **2. An Ideal Conceptual NNP**

We will develop an ideal sustainable NNP based on the Hicksian income concept applied to environmental capital. Our ideal NNP measure will serve as a basis for evaluation of environmental accounting proposals in this chapter and the next.

However, we will not try to operationalize our ideal concept until we have reviewed other attempts in terms of conceptual correctness and feasibility.

As we noted in chapter 4, adjustments to GNP are required in order to derive a sustainable income measure which includes the net depreciation of marketable and nonmarketable natural resources. An adjustment is already made in GNP for the depreciation of reproducible capital. A capital consumption allowance (CCA) is subtracted from GNP to form net national product (NNP). NNP can be viewed as a measure of sustainable output.

The concept of Hicksian income may require other adjustments to traditional NNP due to depreciation, or exhaustion of environmental capital. First, depreciation would include loss of marketable natural resources such as oil (CCAM). This depreciation could be measured by the market value of the loss in resource reserves. Second, depreciation would also include loss of nonmarketable natural capital such as waste disposal capacity (CCAN). This depreciation of nonmarketable natural capital is attributable to the use of the services of environmental capital above and beyond its ability to provide perpetual services. The depreciation allowance for this loss in environmental capital would be the minimum of the social value of its loss or the cost of replacing its services with human-made goods and services. The proper measure of Hicksian income, NNPH, is then:

$$(1) \quad \text{NNPH} = \text{NNP} - \text{CCAM} - \text{CCAN}$$

In contrast to the calculation of CCAM, the determination of CCAN is very difficult because there usually are no market values for public good services of this environmental capital. Analysis of CCAN requires consideration of environmental services and environmental damages. Environmental services [ES] are of two main classes: (1) direct final services such as clean air and aesthetic beauty, and (2) intermediate services, which are of two types, (a) services to other natural systems which in turn provide final products to humans, and (b) services to economic production

processes such as the fishing industry. Environmental damages (ED) are any reductions in the ability of the environment to yield a perpetual level of service. For example, waste disposal into the air does not cause any environmental damages until the capacity of the atmosphere to yield clean air services is depleted. Further waste disposal beyond this point causes environmental damages. These environmental damages are our CCAN, the minimum of the social value of the environmental capital loss or the cost of replacing its services with human-made goods and services. Hence, on the output side of the national accounting framework shown in Table 5-1 below, environmental damages are subtracted from NNP to yield NNPH.

Some subtraction must be made on the input side parallel to environmental damages on the output side to preserve the accounting framework. We can view the input entity for CCAN as the loss in environmental subsidies to production, or the value of the reduction in the ability of the environment to provide services to production. This is a mirror image of the environmental damages; in practice, one may just calculate environmental damages as the measure of CCAN.

Table 5-1 below shows the conceptual framework of our NNPH.

Table 5-1: Accounting Framework for NNPH

<u>Input Side</u>	<u>Final Product Side</u>
GNP as value of inputs	GNP as value of outputs
CCA (-)	CCA (-)
NNP	NNP
CCAM (+/-)	CCAM (+/-)
CCAN (+/-) valued as reduction in ability of envr. to provide services to production	CCAN (+/-) valued as envr damages
NNPH	NNPH

NNPH should be an accurate indicator of the sustainability of current income in terms of marketable and nonmarketable natural resources. The conversion of our ideal NNP into a figure that can be measured will be undertaken in chapter 7 after reviewing current proposals in terms of conceptual correctness and feasibility.

### 3. Aggregation in Measures of Income and Wealth

Aggregation, which sacrifices information by reducing the dimensions of measurement, is appropriate when the use of the aggregates rather than more detailed information would make little difference to the analysis.<sup>79</sup> The benefit of more detailed information is then not worth the cost of interpreting it. Our specific problem is to determine the desirable degree of aggregation in wealth and sustainable income measurements when these concepts must account for the separate dimensions of reproducible and environmental capital, as well as human-made and environmental services.

For monetary aggregation to be appropriate, prices of final goods and services yielding income flows must truly reflect the values of those goods and services. Meaningful prices require perfect knowledge by consumers or the researcher in the case of consumer ignorance. Monetary measurement may be especially a problem in the case of environmental services, where consumers do not know the true value of, say, wetlands' hurricane protection or waste assimilation. Also, allowance for depreciation of capital requires accurate measurement of the full cost of replacing potentially lost income. This measurement may be relatively easy for man-made, reproducible capital that has a market value equivalent to discounted future income flows. However, it may be a special problem for environmental capital, requiring knowledge of possible means and costs of replacement of depreciated capital. It would also require knowledge of the income flows, often derived from unmarketed goods and services, of this capital. If there



is a possibility of large losses due to incorrectly estimating monetary environmental values, then a more disaggregated approach may be necessary.

The appropriate degree of monetary aggregation is dependent on the feasibility of operationalizing concepts of NNP such as that presented in Section 2. As we will see in this chapter and the next, proponents of disaggregated environmental accounting frameworks usually base their arguments at the practical level rather than the conceptual level.

#### 4. Monetary Valuation of Marketable Environmental Capital

Actual NNP does not include the value of the net depletion of marketable natural resource stocks such as oil and gas. Hence some analysts have attempted to value marketable natural resources in order to include their net depletion in the present income accounts in a manner analogous to reproducible capital. We will consider the methods of Landefeld and Hines, and of Salah El Serafy for non-renewable resources. Note that these methods attempt to value and include net depletion of marketable natural resource stocks rather than nonmarketable environmental capital such as air and water. Hence these methods are attempts to include CCAM in our equation (1) into the economic accounts.

Landefeld and Hines use three different techniques to estimate the monetary value of United States oil and gas reserves from 1948-79. The three different methods of monetizing the value of reserves are present value, net price, and land price. Their techniques are also applicable to other nonrenewable marketable resources.<sup>80</sup> Value estimates are only derived for proved reserves, which are quantities of a resource that are known to be recoverable under current economic and technological conditions.

Natural resources, unlike capital, are not totally created by humans; thus there is a rent or net value added attributable to them. Landefeld and Hines measure this rent as

net revenue, the total revenue from the resource minus all factor payments including a normal return to physical capital. The market value of the stock of natural resources is equal to the discounted present value of the stream of net revenue derivable from extracting and selling the resource. The value of a net change in reserves is equal to the change in present value of reserves from one period to the next. This value change is due to the value of new discoveries, depletion, and price changes. Since the present value method requires that future prices, operating costs, production levels, and interest rates on alternative investments be forecast over the life of a given field after its discovery, numerical estimates are very uncertain.

The net price method measures the value of reserves by multiplying the net price, or average net revenue, per unit of the resource times the change in reserves. This method relies on Hotelling's theoretical result that in equilibrium, the net price of resources in the ground should rise as the rate of interest, the rate of return on alternative investments.<sup>81</sup> If equilibrium conditions are maintained, then future price increases would be eliminated in the calculation of the net present value of future cash flows. Hence current net price can be used in valuing natural resource stocks and changes in natural resource stocks. This method differs from the present value method in that it does not require specific assumptions about the future pattern of prices, cost, and rates of return. However, it assumes perfect foresight, a necessary condition for resource markets to be continuously in long run equilibrium. Thus present value estimates of the resource using Hotelling's method may under or overvalue the 'true value' of reserves.

The land price method relies on the theoretical result that in long run perfect competition, the land price of a resource is equal to the present value of the asset. Landefeld and Hines include royalty payments in their land price, and make other adjustments for the fact that much mineral bearing land is leased rather than owned. This method has fewer informational requirements, but is of questionable accuracy due to the great uncertainty of actual mineral value at the time of buying or leasing land.

Landefeld and Hines use all three methods to estimate the value of U.S. oil and gas reserves from 1948 to 1979. Three estimates of the present value method are used corresponding to different assumptions about prices and interest rates. The first estimates are based on a constant real interest rate of 10% and no real increase in the net price over time. The second estimates are calculated with the assumption of long run equilibrium in resource markets with the interest rate equal to the rate of price increase. The third estimates are based on a rough estimate of future market conditions; future prices are assumed to increase or decrease at a rate equal to the average annual change in prices over the last five years. The three present value estimates vary by over fivefold. The net price method yields only one set of estimates due to its assumptions of long run equilibrium.<sup>82</sup> However, due to that assumption, it appears to overvalue future production from 1948-1972 when net prices were falling, and it appears to undervalue future production when net prices were rising rapidly from 1972 to 1978. The land price method also yields only one set of estimates; however, these estimates are unrealistically low until the 1970's, indicating that the price of mineral lands does not fully capture the investment value of the resource. There are two reasons for these low estimates. First, the market for bonus payments is not perfectly competitive, so it is likely that large integrated oil and gas companies have an advantage in buying oil rights from individual land owners. Second, the available data on land prices are incomplete. Firms do not always pay bonuses for future oil extraction when buying land. Furthermore, approximately 34 of oil and gas production from Federal onshore land comes from land that is not competitively leased.<sup>83</sup>

Valuation of natural resource reserves is a necessary condition for their inclusion in the economic accounts. Landefeld and Hines suggest that the value of net depletion be treated analogously to reproducible capital. The appropriateness of adding the net depletion of natural resources to that of reproducible capital depends on the accuracy and volatility of the estimates of natural resources versus manmade capital. Landefeld

and Hines note that the present value estimates of net depletion are far more volatile than those of net depreciation of reproducible capital. For example, in 1970, Alaskan oil discoveries caused the discovery value of oil to increase by a factor of three. This volatility is significant because the net depletion values can be quite large. Some estimates of the value of new discoveries and of depletion would add as much as 27 and 23% to the measures of gross private domestic investment and capital consumption allowances respectively.<sup>84</sup> The net price estimates from 1948 to the 1970's appear to vastly overvalue future production.<sup>85</sup> The land price estimates exhibit less volatility than the alternative estimates with variation approximately the same as for physical capital estimates. However, the estimates themselves appear to be very uncertain indicators of the true value of natural resource reserves. Due to the uncertainties of all three methods and the volatility of the present value and net price estimates, Landefeld and Hines recommend that estimates of the value of natural resource depletion be placed in supplementary series rather than directly in the income accounts.<sup>86</sup>

Salah El Serafy's valuation technique is a simple version of the present value method, but his method of including the value of net natural resource depletion in the accounts is different from that of Landefeld and Hines. El Serafy rejects the procedure of subtracting the value of net depletion from GNP to form an NNP. Instead, he attempts to divide the net revenue from mineral extraction into an income element which should count in GNP and a capital element which should not.<sup>87</sup> His proposal is based on the Hicksian conception of income as that part of revenue which can be consumed while leaving the earner as well off at the end of the accounting period as at the beginning. A nonrenewable asset has some finite lifetime over which it yields net revenue,  $R$ , per period. Some portion of the net revenue from this asset must be put aside and reinvested elsewhere if the owner is to have constant income over an infinite period,  $X$ .  $R-X$  is the 'user cost' or 'depletion factor' that should be set aside as a capital investment and totally excluded from GNP.

El Serafy equates the present value of a constant and finite stream of receipts  $R$  to the present value of a constant and perpetual stream of income  $X$  in order to determine  $(X/R)$ , the percent of receipts that should be considered income. The present value of the finite series  $R$ , accruing in equal amounts over a period of  $n$  years, is:<sup>88</sup>

$$R^* = \frac{(R) \left[ 1 - \frac{1}{(1+r)^{n+1}} \right]}{1 - \frac{1}{1+r}}$$

The present value of the infinite series  $X$  is:

$$X^* = \frac{X}{1 - \frac{1}{1+r}}$$

The perpetuity equivalent of  $R$  is:

$$X = R \left[ 1 - \frac{1}{(1+r)^{n+1}} \right]$$

The percent of receipts that should be considered as income is:

$$X/R = 1 - \frac{1}{(1+r)^{n+1}}$$

The percentage of receipts that can be considered as true sustainable income depends only on the interest rate and the life expectancy of reserves. There is no need to predict future prices because price is in the numerator and denominator of  $X/R$ ; thus future price changes cancel out leaving the same ratio of income to receipts. The longer the lifetime, and the higher the interest rate, the greater the percentage of net receipts that can be considered income. El Serafy notes that the current practice of counting all exhaustible resource revenues as income ( $X/R = 1$ ) means that either  $n$  approaches infinity or the discount rate is very high. Since neither of these two conditions is likely to hold in the real world, present accounting techniques for natural resources include some capital

consumption as income. Table 5-2 below shows the ratio  $X/R$  for a number of different discount rates and oil reserve life expectancies.

Table 5-2: Proportion of Receipts from Oil Sales that should be Considered Income<sup>89</sup>

<u>Life Expectancy (years)</u>	<u>Real interest Rate (% per annum)</u>			
	<u>1</u>	<u>2</u>	<u>5</u>	<u>10</u>
-				
15	.15	.27	.52	.78
20	.19	.34	.62	.86
30	.27	.46	.77	.95
40	.34	.56	.86	.98
50	.40	.64	.91	.99

For example, if the net revenue of oil reserves increased by \$100, and the country has a 30 year life expectancy of oil reserves and a 5% discount rate, the sustainable income from the reserve is \$77. The capital consumption allowance for depletion would be \$23. This could be reinvested elsewhere at a return  $r$  to ensure income after the reserve is exhausted. In El Serafy's method, only part of the value of new discoveries is considered as income. El Serafy advocates that the income from nonrenewable resources be entered directly into GNP rather than in supplementary series.

Now we will compare El Serafy's method to Landefeld and Hines in terms of the size of the depletion allowance, theoretical correctness as a Hicksian income measure, and volatility relative to the conventional accounts. El Serafy's method will result in a lower deduction from, or addition to, GNP than the value of net depletion used by Landefeld and Hines. Landefeld and Hines would add the total present value of a new discovery to GNP whereas El Serafy would only add a percentage of that total present

value. Similarly, Landefeld and Hines would subtract the total present value of depletion whereas El Serafy would only deduct a percentage of that total present value. Landefeld and Hines consider all net depletion as a capital loss, while El Serafy views some of net depletion as capital consumption and some as income.

El Serafy's method is the better approximation of sustainable income because it only deducts from exhaustible resource revenues an amount necessary to maintain a constant real income after the resource is depleted. This methodology follows directly from the Hicksian income concept. If net depletion is negative (new discoveries are greater than depletion), the method of Landefeld and Hines will not deduct an amount from the new discoveries that is necessary to maintain a constant real income after the resource is exhausted. If net depletion is positive, the method of Landefeld and Hines will deduct a depletion allowance that is larger than needed to maintain a constant real income after the resource is exhausted. Only part of the value of net depletion needs to be reinvested elsewhere in order to achieve a constant stream of income after the resource is exhausted. The crux of the Hicksian income concept is a constant level of purchasing power over time.

El Serafy's method must add similar volatility into the accounts as the present value estimate of Landefeld and Hines because they both begin with the same present value of a finite resource.<sup>90</sup> The volatility of El Serafy's estimates may affect the present capital consumption allowances less only because a smaller deduction is made in the income series. Due to new mineral discoveries, price and interest rate changes over time, and uncertainties in the calculation of depletion times, there would be wide swings in the income from mineral resources using either his method or those of Landefeld and Hines.<sup>91</sup> Hence all the methods of natural resource valuation and inclusion in the accounts will lead to increased volatility in the GNP time series. The basic difference between El Serafy's position and that of Landefeld and Hines is that El Serafy appears more willing to tolerate the greater swings in value due to inclusion of net natural

resource depletion in the income accounts. The tradeoff in the inclusion of the value of net depletion of natural resource capital in the accounts is between more accurate assessment of income and capital consumption versus more variance in GNP over time.

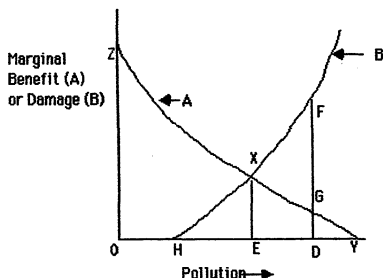
The above techniques were developed to value the depletion of nonrenewable resources. However, the present value method is also used to value renewable natural resources. It is necessary to value them in order to include the net depletion of their capital stocks in income accounts. For example, the United Nations guidelines suggest that the value of timber tracts should be based upon market prices where available. These capital assets prices should reflect the present value of future income flows. If there have been insufficient market transactions to provide a base for estimation, standing timber should be valued by discounting the future proceeds of selling the timber at current prices after deducting management and harvest costs.<sup>92</sup> At present, expenditures by humans on afforestation are considered part of reproducible capital and placed in the income accounts. But natural growth less depletion of timber is placed in the reconciliation accounts mentioned in chapter 4. Once the renewable asset is valued, then inclusion in the income accounts would require an entry for the value of net depletion of timber. This capital consumption allowance is the measure of the current sacrifice necessary to retain a sustainable flow of services from a renewable resource. The United Nations inclusion method is the same as that of Landefeld and Hines; the present value of net depletion of capital is subtracted from gross income. El Serafy's method for including income from exhaustible resources is not needed for a renewable resource because the capital consumption allowance is simply the value of the net loss in the stock of a resource with infinite life rather than finite. Note that the capital consumption allowance for renewable resources can result in an addition to GNP if human action increased the sustainable flow of services from a resource. For example, a change in market structure from competition to monopoly in fishing may result in a larger stock of fish capital and hence a larger flow of sustainable services.



## 5. Monetary Accounting Frameworks and Valuation of Nonmarketable Environmental Capital

This section reviews Henry Peskin's conceptual framework for the inclusion of nonmarketable environmental capital services into the national accounts.<sup>93</sup> We will present his approach, compare it at the conceptual level to our ideal NNP, and then consider practical problems of valuing environmental services and environmental damages. The conceptual basis for Peskin's modification of the accounts is the recognition of air and those portions of land and water which are not privately owned as nonmarketable environmental capital. For example, clean air provides valuable disposal services to firms, and clean air provides consumers with life support, good health, and aesthetics. Wetland ecosystems provides services such as hurricane protection, aesthetics, and biodegradation of pollutants in addition to providing habitat for marketable natural resources. Nature's services are not usually bought and sold in the marketplace, so shadow prices must be estimated for these services.

**Figure 5-1: Marginal Pollution Benefit and Damage**



Peskin portrays his conceptual framework using Figure 5-1 above.<sup>94</sup> For example, consider the value of the environment's waste disposal services. As a polluter dumps residuals, the marginal social benefit curve can be described by curve A in Figure 5-1. Curve A, the marginal benefit function, equals the marginal production cost savings to a firm, were the polluter allowed free access to environmental services of waste disposal. Curve A captures all cost savings from the use of the environment's disposal services. In the absence of any effort to reduce pollution, private firms would pollute to point Y. Controlling pollution to point D results in increased firm production costs of GDY. This may include input or production changes, or direct end-of-pipe pollution control expenditures. Curve A is downward sloping if diminishing returns to the environmental input, say clean air, is assumed. Curve B is the marginal damage function from the use of the environment's disposal services. Curve B captures all social damages including costs to individuals and increased production costs for some firms due to pollution.<sup>95</sup> This curve has an increasing slope if it is assumed that damage increases more than proportionately to the physical amount of pollution. For any amount of pollution, we can determine the total environmental damages, total services, and the difference between them. For example, at point D, the total social damage is represented by the area HFD, and the total service is represented by the area OZGD. The difference between them is the net social gain from pollution level D. Of course, it would be maximized at E.<sup>96</sup> As we will soon see, these three numbers correspond to three new environmental entries in Peskin's accounting proposal.

Peskin departs from the conventional accounts by adding a Nature sector which produces all environmental services [ES], area OZGD in Figure 5-1, and uses as inputs the environmental damages [ED], area HFD. Two entries and a balancing term are added to the traditional income accounts in Peskin's framework. One entry describes the productive services that the environment provides to users of environmental services,

area OZGD. This entry is placed on the left hand (income and non-income charges) side of the consolidated national account along with the other productive inputs such as labor. It has a negative sign because it is a subsidy to users, i.e. reduces the need for other inputs. The second entry is the environmental damages resulting from the use of the environment, area HFD in Figure 5-1. The environmental damage entry is placed on the right hand side of the consolidated national accounts along with the other components of output.<sup>97</sup> Its sign is negative reflecting the fact that the value of environmental damages is negative.<sup>98</sup> Since, in general, these two entries will not be equal, a balancing entry will be required. This term, net environmental benefit (NEB), is entered on the left hand side of the national accounts. It is equal to environmental services minus environmental damages, or OZGD minus HFD in Figure 5-1. It may be positive or negative.

Table 5-3 below shows the consolidated national accounts in Peskin's proposed framework.

Table 5-3: Consolidated National Income and Product Account<sup>99</sup>

<u>Input</u>		<u>Output</u>
1. Compensation of employees and proprietors (incl. rent income)		14. Personal consumption
2. Profits with inventory valuation and cap consump. allowance		15. Gross private domestic invest.
a. Profits tax		16. Exports
b. Profits after tax		17. Imports
c. Invent valuation & CCA		18. Governmental goods/services
3. Net interest		
NATIONAL INCOME		
5. Transfer payments		
6. Indirect taxes		
7. Subsidies(-)		
8. Statistical discrepancy		
NET NATIONAL PRODUCT		
10. Capital consumption		
CHARGES AGAINST GROSS NATIONAL PRODUCT	=	GROSS NATIONAL PRODUCT
12. Environmental services(-), [ES]		19. Environmental damages(-), [ED] <sup>100</sup>
a. Air		a. Air
b. Water		b. Water
c. Land		c. Land
13. Net environmental benefit(+/-), [ES-ED]		
CHARGES AGAINST MODIFIED GROSS NATIONAL PRODUCT	=	MODIFIED GROSS NATIONAL PRODUCT

Peskin considers three modified definitions of GNP that arise from this model; we will describe them and compare them with our NNPH as theoretical approximations of sustainable production and income. Although his modifications are described in terms of GNP, we can still compare them to our NNPH because the only difference between GNP and NNP is the reproducible capital consumption allowance on line 10 of Table 5-3. Peskin himself notes that his adjustments can be made at the level of NNP or GNP.<sup>101</sup> We will not evaluate Peskin's model in terms of CCAM (for marketable natural resource capital depreciation) because his framework is not meant to apply to such resources. Note that Peskin's environmental services is a total valuation of all environmental services as inputs to production, whereas our environmental services in NNPH describe all final and intermediate services of nature. We will note this distinction in the last two of Peskin's three GNP modifications. Now we will consider Peskin's three adjustments to GNP.

Peskin's first adjustment is placed in equation (2) below:

$$(2) \text{ GNP1} = \text{GNP} - \text{ED}$$

As a conceptual measure of sustainable income, GNP1 is an improvement over GNP in that it subtracts from GNP the value of environmental damages, a measure of the loss of environmental capital due to current economic production. Since Peskin's ED are equal to our CCAN, GNP1 is the same as our ideal measure, NNPH.

Peskin's second adjustment is placed in equation (3):

$$(3) \text{ GNP2} = \text{GNP} + \text{ES}$$

Due to Peskin's definition of ES as all environmental services provided as inputs to human production, GNP2 is a measure of total human and natural productive capacity. GNP2 does not provide a sound Hicksian income measure because it does not tell us how much of GNP we can continually consume without impairing the total human-made and natural capital stock. GNP2 provides a measure of the gross natural contribution to

production without subtracting for depreciation of natural capital caused by economic activities already counted in GNP.

Peskin's third adjustment is placed in equation (4):

$$(4) \text{ GNP3} = \text{GNP} + \text{NEB}$$

where:

$$\text{NEB} = \text{ES} - \text{ED}$$

Due to Peskin's definition of ES as all environmental services provided as inputs to human production, GNP3 is a measure of human-made production plus a perpetual level of environmental services. NEB tells us the latter information because total environmental services minus environmental damages is the amount of services that can be used year after year. If we consider all of Nature and the human economy as one system, then GNP3 could be viewed as a measure of sustainable system output. However, we desire a less ambitious measure of the sustainable economic output; this requires adjustment to the current economic measure, GNP, by the net amount of environmental capital depreciation in a given year. This measure is provided by GNP1 or NNPH. Virtually no economists believe that a monetary measure of total system output such as GNP3 is possible in the foreseeable future.

In sum, GNP1 may be the best of Peskin's three definitions by the Hicksian income criterion because it subtracts from GNP a capital consumption allowance for the value of the loss of services (environmental damages) of nonmarketable environmental capital. Hence GNP1 could be consumed year after year without reducing the total income to society.

Before considering valuation problems in implementing Peskin's framework, we will note a difficulty in his framework and also our own NNPH. This difficulty is the treatment of PAC expenditures. As we noted in chapter 4, PAC expenditures (expenditures designed to control pollution) are treated in GNP as final products if they are undertaken by the government but as intermediate products if they are undertaken

by the business sector. Hence the present GNP is inconsistent in its treatment of PAC expenditures; government PAC are added to GNP while business PAC are netted out as intermediate products. PAC expenditures are now calculated separately so they are a logical candidate to use as at least a partial measure of environmental damages. If we use PAC expenditures as such a measure, then our new national income measure will always be ambiguous because it is derived from a GNP which treats PAC expenditures in an inconsistent manner. Hence the solution would appear to be to take PAC expenditures completely out of the present GNP, and then use them to measure environmental damages which would be subtracted from GNP according to our formula for NNPH. We will consider this problem further in chapter 7 after we have reviewed all the aggregated and disaggregated environmental accounting proposals.

Now that we have presented Peskin's conceptual framework and compared it to NNPH, we will consider some of the valuation problems involved in implementing his framework. Since his figures require similar information as our ideal NNP, this discussion will also show some of the difficulties involved in operationalizing our NNPH.

The most difficult part of Peskin's accounting proposal would be the measurement and valuation of environmental services and damages. Peskin advocates the range of techniques used in cost-benefit analysis to derive shadow prices for unpriced natural goods. Measures of environmental damages require estimates of the minimum of the cost of replacing lost environmental services or of the environmental benefits lost. The theoretically correct measure of loss is the consumer's willingness to pay to avoid the environmental damage. In practice, the willingness to pay method involves estimates of dollar costs of pollution such as the health and property damages from pollution.<sup>102</sup>

The value of environmental services can be estimated using similar techniques. Value is viewed in terms of 'damage' that would result if the polluter were denied the environmental services. The 'damages' in this case are the minimum of the cost to the

polluter and society of the resources that must be substituted for the services that were being provided free of charge by the environment or of the value of benefits lost.<sup>103</sup> As we noted earlier, the value of environmental services includes all social costs of economic actors doing without the environmental functions such as disposal of wastes.

Direct costs of pollution control are likely to undervalue the 'true value' of free environmental services because they ignore changes in inputs and final products due to pollution control, and disposal is only one of many environmental functions that have value to humans. For example, suppose regulations are placed on a firm currently dumping pollutants into the air. Then direct costs of pollution control, or PAC expenditures, usually only include 'end of the pipe' abatement and control. But there are other costs to the polluting firm due to the regulations such as changes in plant organization, product mix, and total output changes. The total costs of adjusting to a smaller use of the 'air' input are larger than the PAC expenditures themselves.

Peskin presents some crude estimates of environmental services and damages for the United States from 1972 to 1978.<sup>104</sup> The only type of environmental services for which national estimates of value were available was disposal services of air and water pollution. Thus he confines his environmental damages to estimates taken from various studies of national air and water pollution sponsored by the Environmental Protection Agency. Peskin computes GNP and the various alternative GNP definitions for the years 1972 and 1978. Table 5-4 below shows his results.

Table 5-4: Comparison of Modified GNP and GNP in 1972 and 1978<sup>105</sup>

	1972 constant \$	1978 constant \$	Change 72 to 78	% ch.
ES	45.9	27.1	-18.8	-41.0
ED	30.0	20.5	-9.5	-32.0
NEB	15.9	6.6	-9.3	-58.0
GNP	1171.0	1399.2	228.2	19.0
GNP1	1141.0	1378.7	237.7	21.0
GNP2	1216.9	1426.3	209.4	17.0
GNP3	1186.9	1405.8	218.9	18.0



By any of the alternative definitions, the difference between conventional GNP and modified GNP is small for both 1972 and 1978. However, the estimates of environmental services and damages are so crude and incomplete that few conclusions can be drawn. Many environmental services and corresponding damages, such as aesthetics and recreation, were not covered in the data. The few environmental services and damages included in the data are rough estimates based on extrapolations of smaller scale studies of air and water pollution which are not all consistent in methodology, time periods, or statistical techniques. The estimates often represent the costs of applying specific technologies, which may not be the least cost method for all firms. Hence, Peskin notes that the environmental damage estimates may be high or low by a factor of two or three.<sup>106</sup> Due to the crude and incomplete nature of the estimates of environmental services and damages, the figures in Table 5-4 are primarily illustrative examples of Peskin's accounting framework. Much further research would be required to calculate comprehensive estimates of the entries in this accounting structure.

The primary advantage of any accounting approach which uses monetary valuation of environmental capital compared with other more disaggregated approaches is that it allows integration of environmental problems directly with the monetary aggregates that make up the other components of income. However, the biggest problem is the feasibility of valuing environmental services and damages in dollars with enough accuracy to be valid for policymakers. Integration of environmental phenomena directly into the economic accounts is considered desirable but not possible by many researchers.<sup>107</sup> Some of the major problems encountered in attaching monetary values to environmental phenomena are: (1) lags between the environmental effect and the effect on human health and ecosystems; this heightens cause and effect uncertainties and makes the calculation of the present value of damage costs very difficult. (2) People affected by pollution are often ignorant of the full range of environmental capacities so their preferences will reveal little of the true value of the

environment to them. In many cases, scientific knowledge itself is imperfect; we must base our decisions on a very limited knowledge of ecosystems, their interactions, and their ultimate value to us. (3) There is the possibility that, at some threshold levels, the direct value to humans of some environmental functions may be infinite or irreplaceable.<sup>108</sup> An incomplete valuation or lack of recognition of such a resource could lead society to unknowingly deplete irreplaceable or infinitely valued environmental capital, and permanently alter sustainable income levels. In such cases, we may need a distinction between two types of environmental services: replaceable and irreplaceable. The replaceable ones could be valued in monetary terms and we could measure the proximity of the irreplaceable ones of sufficiently high value to threshold levels.

Due to severe valuation problems, many analysts believe that GNP should be simply linked with supplementary information provided in the form of a series of physical, chemical, and biological indicators on state of the environment. This technique, which abandons conventional aggregated monetary income measures in favor of a multi-dimensional income measure to assess sustainability, is the subject of chapter 6. As Peskin notes, such a complex technique runs the risk of being ignored by policy makers when making economic decisions that seriously affect the environment. Although it may not be possible to implement an accounting framework as comprehensively as necessary to include all environmental services and damages in monetary terms, it does seem vital to develop meaningful monetary links between environmental phenomena and conventional economic income measures such as GNP and NNP.

#### 6. Mass-Energy-Balance Accounting

The mass-energy- balance (MEB) approach originated with Robert Ayres and Allen Kneese in 1969.<sup>109</sup> They argued that externalities associated with disposal of

residuals from production and consumption activities were an inevitable part of the economic process due to the first law of thermodynamics, the conservation of mass and energy. These negative externalities were unimportant when wastes were small relative to the natural absorption capacity of the environment. Society now needs to determine the amounts of residuals, the industrial processes which create residuals, and the damage costs to choose a rational allocation between market goods and scarce environmental goods. The MEB approach is directed toward the physical specification of raw material flows and pollutants; this specification is a necessary, but not sufficient, condition for the valuation and inclusion of natural resources in the income accounts.

The material-energy-balance approach views environmental pollution and its control as a balance problem for the entire economy. The economy is seen as a unidirectional set of transformations of physical materials and energy from the raw state through successive stages of extraction and processing to 'final' goods and services, and ultimately to waste flows. Due to the first law, in a closed economy (no imports or exports), the sum total of material and energy extracted from the natural environment as raw material must exactly balance the sum total of materials and energy returned to the environment as waste flows, less any accumulation in the form of capital stocks and inventories. The primary purpose of the MEB accounts is to trace the extraction and transformation of material and energy from natural resources through various successive stages of processing to final use, and thence back to the environment as waste.<sup>110</sup> This framework would provide a data base for large-scale models of environmental forecasting and management. Hence policymakers could determine the total emissions of pollutants such as carbon dioxide and chlorofluorocarbons, and their distribution by industrial process and geographical location.

The fundamental design principle of the MEB accounts is the conservation of material and energy. A gross volume balance is applied in the case of production, consumption, and trade of major resources and commodities. This is similar to a

conventional balance sheet. It lists opening stocks, changes such as consumption, net exports, and closing stock. However, it includes production, consumption, import, and export figures for such hazardous waste materials as DDT, chlorinated biphenyls, fluorocarbons, and mercury. These waste materials are not accounted for in conventional balance sheets. A more refined material and energy balance, by process, is also applied to show the relation between resource/commodity production and consumption and the generation of waste flows. The classification of material and energy use by production process allows for differences in the technologies used in various extractive industries. The same extractive industry may have different residuals generation and environmental impact depending on the technology used in processing the raw materials. The organization of industries by production processes requires extensive, detailed information on different production technologies.

Kneese and Ayers implemented the MEB approach in a study of the United States beet sugar industry.<sup>111</sup> They used the beet industry to illustrate the MEB technique because this industry's processes were relatively simple. A complete materials balance was estimated for representative plants using different processes to estimate different amounts of residuals generation and environmental impacts. At present, cost prohibits estimation of complete MEB accounts for entire economies.<sup>112</sup>

The MEB accounts are not a complete solution to the problem of incorporating net depletion of natural resources into income measures. First, since they focus on material-energy balances, the MEB accounts are primarily concerned with volume pollutants (such as organic wastes or combustion products) plus specific major chemicals and metals. Their emphasis on weight causes them to neglect low volume pollutants with serious health effects, and 'qualitative' pollutants not subject to conservation rules such as noise, or aesthetic decay. Second, they do not consider the environmental impacts on human health and ecosystems.<sup>113</sup> Third, even if the MEB accounts supplied all physical information on environmental impacts, they do not provide

a methodology for valuing these impacts, a necessary condition for linking them to the economic accounts.<sup>114</sup>

## 7. Energy Accounting

Energy analysis attempts to measure marketed and nonmarketed energy flows in economic and ecological systems, and to connect energy accounting units with economic value.<sup>115</sup> This methodology is important for the inclusion of environmental factors in income accounts because it may provide an easier method of valuation than the traditional willingness to pay. Energy analysis calculates the embodied energy (sum of the direct and indirect energy inputs = total energy cost of a good) required to produce goods and services. These energy costs have been determined for sectors of the U. S. economy comparable to the sectors in the monetary IO table. The step from energy value to economic value is made by multiplying the embodied energy costs for each sector in an energy IO table by some measure of dollars of economic activity generalized per unit of total energy input. If the latter measure is relatively constant over time, the economy is presumed to operate on an energy theory of value. Costanza and Herendeen found that the embodied energy cost of goods was highly correlated with total dollar value of output for 87 sectors of the U.S. economy in 1963, 1967, and 1972.<sup>116</sup> The energy analysis method is based on the hypothesis that, since embodied energy and value to society are correlated for market goods, then the embodied energy in nonmarketed environmental systems can be used to estimate the value to society of the nonmarketed goods.<sup>117</sup>

The explicit link between energy and dollar units is important. If energy flows can be measured for environmental services and meaningfully translated by a constant conversion factor to dollar amounts, then there would be another method to measure shadow prices for nonmarketed ecological services which may be easier than the

estimation of dollar values by traditional cost-benefit methods. Energy accounts, which are then directly related to human welfare, can be used to value nonmarketed and marketed environmental capital in dollar terms which allows the depletion of nonmarketed environmental capital to be incorporated into income measures. For example, one could estimate biological productivity of an area converting the plant production to fossil fuel energy equivalents and then to economic value using the constant relation between energy consumption and economic value in the economy as a whole.<sup>118</sup>

There are three problems with energy analysis that lessen its usefulness as a comprehensive tool for valuation of nonmarketed environmental capital and service flows. First, the constant historic correlation between embodied energy and economic value uses GNP as a proxy for economic value. The dollar equivalent of embodied energy is usually derived using an economy-wide ratio of economic value per unit of energy, usually the ratio of GNP to total embodied energy.<sup>119</sup> But GNP does not accurately measure 'value' since it excludes externalities and free goods (environmental services, pollution, etc.). A modified economic measure which calculates true economic value (GNP- net depletion of environmental capital) is the preferred measure to obtain the dollar equivalent of energy. Over time, the current  $GNP/Total\ embodied\ energy$  may move independently of a more accurate measure of corrected  $GNP/Total\ embodied\ energy$ . Hence the derivation of dollars values for embodied energy using conventional GNP may cause inaccurate estimates of the value of nonmarketed environmental capital.

A second criticism of energy evaluation is that true economic value may be completely independent of embodied energy in some cases. As Peskin has bluntly stated, "The reason a Rembrandt painting is more valuable than a Picasso drawing is not because oil paint contains more BTU's than ink."<sup>120</sup> The energy theory of value is more appropriate for material goods and services where price = marginal cost, or at least price/marginal cost is constant across goods and services.<sup>121</sup> Then, assuming long run

competitive equilibrium conditions, a cost-based valuation technique such as energy analysis may accurately estimate subjective value of humans.

A third problem of energy evaluation is the assumption that, since embodied energy and value to society are correlated for marketed goods, then embodied energy can be used to estimate values for nonmarketed goods. Although some nonmarketed goods such as wetlands clearly have value to humans, it is uncertain that all natural resources with large amounts of embodied energy would also be valued highly by humans in a perfectly informed society. For example, hurricanes have huge stores of embodied energy, but their social value is highly uncertain. In general, energy analysis may be a very inaccurate estimate of environmental capital values because the concrete forms (grass, water, etc.) in which energy is embodied may have very different, and unknown values, since the forms are not marketed. For example, energy analysis may include natural productivities that have very little value to society.<sup>122</sup>

These criticisms are compelling, and thus, at its present state of development, energy analysis cannot serve as an all purpose valuation technique for nonmarketed environmental capital. However, energy analysis has important uses independent of the debate over the relation of embodied energy to economic value. Clearly, energy is necessary for the production of many goods of economic value, and energy use creates pollutants of great negative value. The calculation of total energy costs of goods is useful for determining what products are causing the significant environmental impacts of energy production and use and thus where conservation measures could be effectively applied.

## 8. Summary

In this chapter, we have attempted to provide a conceptual framework based on Hicksian income for the inclusion of the net depletion of marketable and nonmarketable natural resources in the income accounts. We then used our framework as a basis to analyze various attempts to include these factors.

The first major adjustment required to GNP in order to approximate our NNPH is a depletion allowance for marketable natural resources (CCAM) such as oil. We investigated two methods of calculating this depletion allowance by El Serafy and Landefeld and Hines. The latter method treats net depletion of marketable natural resources in a manner analogous to capital consumption allowances for reproducible capital; all net depletion is a capital loss. El Serafy's approach divides net depletion into two components: capital loss (amount which must be reinvested to maintain constant real income) and income which can be spent without lowering sustainable living standards. We argued that El Serafy's method yields a better approximation of Hicksian income because it only deducts from exhaustible resources revenues an amount necessary to maintain a constant real income after the resource is depleted. Both methods are feasible with existing data on resource prices, interest rates, and reserve stocks. However, the estimates of CCAM by either method may change greatly from one year to the next depending on interest rates, resource prices, technological changes, and new discoveries. Hence estimates of CCAM such as for United States oil and gas by Landefeld and Hines are likely to be more volatile and less accurate than the CCA for reproducible capital. This does not imply that the calculation of CCAM is useless; rather, it is an argument for placing CCAM in a subsidiary series rather than directly into the current accounts.

The second and last major adjustment required to GNP in order to approximate our NNPH is a depletion allowance for non-marketable natural resources (CCAN) such



as wetlands. We investigated Henry Peskin's method of including nonmarketable environmental capital into the economic accounts. His GNP1 is the same as our NNPH because our measure of CCAN is equal to environmental damages (ED) in Peskin's framework. Although Peskin is not exclusively concerned with sustainable income in developing his three different GNP measures, his GNP1 can be viewed as a correct extension of the accounts to provide a Hicksian income measure which includes nonmarketed environmental capital.

After examining Peskin's framework and comparing it to our NNPH, we considered the feasibility of actually estimating CCAN to provide empirical Hicksian income measures. The practical problems of valuing nonmarketable natural resources are significant, and these problems are accentuated by the possibility of large losses due to incomplete valuation or lack of recognition of critical natural resources. These problems have caused some analysts to develop disaggregated accounting frameworks which do not monetize the value of all nonmarketable environmental capital. These efforts will be considered in the chapter 6.

Two other aggregated approaches were considered in this chapter: mass-energy-balance (MEB) accounting and energy accounting. The MEB approach may be a necessary part of a comprehensive approach to valuation of natural resources, but it does not consider the critical valuation problems mentioned above. Energy analysis solves the valuation problem through the use of assumptions (such as the correlation of embodied energy and economic value for all goods) which are unacceptable to many analysts. There is also a circularity problem in the use of GNP as an energy-dollar conversion measure in valuing non-marketable natural resources in order to correct GNP for environmental deficiencies.

The most important thing we learned in this chapter was the proper conceptual framework for Hicksian income measures which include environmental capital. The critical unresolved issue is the feasibility of implementing such conceptual frameworks

for nonmarketable natural resources. Chapter 6 will consider the approaches which have abandoned the attempt to include all environmental factors in monetary terms. Thus chapters 5 and 6 should allow us to develop a feasible approach to the determination of NNPH. We will develop our approach in chapter 7 after reviewing the advantages and disadvantages of the aggregated and disaggregated methods.

<sup>79</sup>H. A. John Green, Aggregation in Economic Analysis (Princeton, New Jersey: Princeton University Press, 1964), p. 3.

<sup>80</sup>J. Steven Landefeld and James R. Hines, "National Accounting for Non-Renewable Natural Resources in the Mining Industries," Review of Income and Wealth, Series 31, No. 1, (March, 1985), p. 1-20.

<sup>81</sup>Harold Hotelling, "The Economics of Exhaustible Resources," Journal of Political Economy, Vol. 39, (1931), p. 137-175.

<sup>82</sup>The net price estimates are the same as the present value estimates which assume long run equilibrium in resource markets.

<sup>83</sup>J. Steven Landefeld and James R. Hines, "National Accounting for Non-Renewable Natural Resources in the Mining Industries," pp. 13-14.

<sup>84</sup>*Ibid*, p. 17.

<sup>85</sup>*Ibid*, p. 18.

<sup>86</sup>*Ibid*, p. 2.

<sup>87</sup>Salah El Serafy, "The Proper Calculation of Income from Depletable Natural Resources," UNEP-World Bank Environmental Accounting Workshop, World Bank, November 17-18, 1986, Washington, D. C..

<sup>88</sup>*Ibid*, pp. 24-25. In the following formulation, it is assumed that the receipts  $R$  accrue at the beginning of each accounting period.

<sup>89</sup>Salah El Serafy, "Absorptive Capacity, The Demand for Revenue, and the Supply of Petroleum," The Journal of Energy and Development, Vol. 7, No. 1, (Autumn, 1981), p. 86.

<sup>90</sup>This assumes that the two methods use the same assumptions in calculating the present value of net revenues from an exhaustible resource.

<sup>91</sup>Although price changes will not affect El Serafy's  $X/R$  ratio, price changes will still cause the absolute measures of income to change from period to period.

<sup>92</sup>Department of Economic and Social Affairs, Provisional International Guidelines on the National and Sectoral Balance-Sheet and Reconciliation Accounts of the System of National Accounts, Series M, No. 60. (New York: United Nations, 1977), pp. 48-49.

<sup>93</sup>Henry Peskin, "National Income Accounts and the Environment," in Environmental Regulation and the U. S. Economy, Edited by Henry Peskin, Paul Portney, and Allen Kneese. (Baltimore, Maryland: John Hopkins University Press, 1981), pp. 77-103.

<sup>94</sup>Henry Peskin and Janice Peskin, "The Valuation of Nonmarket Activities in Income Accounting," Review of Income and Wealth, Series 24, No. 1, (March, 1978), pp. 74-76.

<sup>95</sup>There may be producer losses from pollution in the environmental damage curve, just as there may be producer gains in the environmental service curve. The important point is that the environmental damage curve measures all damages to all parties from the use of the environment, and the environmental service curve measures all benefits to all parties from the use of the environment. This point is seen in Peskin's separate delineation of environmental services and damages for the industry, government, and household sectors. All sectors contribute to the sum total of environmental damages and services in the national income accounts in Peskin's model. See Henry Peskin, "National Income Accounts and the Environment", pp. 86-89.

<sup>96</sup>This table can be interpreted in terms of marginal valuations. However, Peskin uses total valuations because the actual estimates of environmental services and damages are calculated in total values which include consumer and producer surplus. Marginal valuations are of course used in the calculation of value for ordinary marketed goods. See Henry Peskin and Janice Peskin, "The Valuation of Nonmarket Activities in Income Accounting", pp. 75 and 84.

<sup>97</sup>Peskin notes that policy changes could cause the value of environmental services and damages to be reflected in ordinary accounting. For example, if complete effluent charges were imposed on business, the value of the environmental services would be reflected in the present accounting system. Similarly, if polluters were required to pay full compensation to consumers suffering environmental damage, then no additional output entry would be required. However, his discussion of environmental additions to the present accounting system assumes that such a full coverage fee-compensation scheme does not exist. See pp. 84-85 of Henry Peskin, "National Income Accounts and the Environment".

<sup>98</sup>Henry Peskin and Janice Peskin, "The Valuation of Nonmarket Activities in Income Accounting", p. 80.

<sup>99</sup>"National Income Accounts and the Environment", p. 90.

<sup>100</sup>Note that Peskin's environmental damage entry is equal to the CCAN entry used in the determination of our ideal Hicksian income measure, NNPH.

<sup>101</sup>Henry Peskin, "National Income Accounts and the Environment", p. 91.

<sup>102</sup>Henry Peskin and Janice Peskin, "The Valuation of Nonmarket Activities in Income Accounting", p. 84. An alternative to estimates of direct dollar costs is the contingent valuation method. For a review of this method, see the following: R. G. Cummings, D. S. Brookshire, and W. D. Schulze, Valuing Environmental Goods: An Assessment of the Contingent Valuation Method (Totowa, New Jersey: Rowman & Allanheld, 1986).

<sup>103</sup>Henry Peskin and Janice Peskin, "The Valuation of Nonmarket Activities in Income Accounting", p. 84.

<sup>104</sup>Henry Peskin, "National Income Accounts and the Environment", p. 100.

<sup>105</sup>*Ibid.*, p. 100. Figures are in billions of dollars.

<sup>106</sup>*Ibid.*, p. 94.

<sup>107</sup>Oris Herfindahl and Allen Kneese, "Measuring Social and Economic Change: Benefits and Costs of Environmental Pollution," in The Measurement of Economic and Social Performance, Edited by Milton Moss. (New York: Columbia University Press, 1973), p. 449.

<sup>108</sup>This possibility does not imply no tradeoff between an environmental good and market production. Rather, there may be a tradeoff up to some depletion level of the environmental good, and then no tradeoff as the costs of environmental losses become infinite.

<sup>109</sup>Robert Ayres and Allen Kneese, "Production, Consumption, and Externalities," American Economic Review, Vol. LIX, No. 3, (June, 1969), pp. 282-297.

<sup>110</sup>United Nations Economic and Social Council, Draft Guidelines for statistics on materials/energy balances (New York: United Nations, 1976), p. 9.

<sup>111</sup>Allen Kneese, Robert Ayres, and Ralph d'Arge, Economics and the Environment: A Materials Balance Approach, (Baltimore: The Johns Hopkins University Press, 1970), pp. 45-51.

<sup>112</sup>Department of International Economic and Social Affairs, Survey of Environment Statistics: Frameworks, Approaches and Statistical Publications, Series M, No. 73. (New York: United Nations, 1982), p. 9.

<sup>113</sup>Draft Guidelines for statistics on materials/energy balances, p. 11.

<sup>114</sup>Kneese and Ayres recognized the importance of developing improved measures of the external costs resulting from differing concentrations and durations of residuals in the environment. However, such valuation is not an integral part of the MEB approach. See the following article: "Production, Consumption, and Externalities", p. 288.

<sup>115</sup>The methodology of energy analysis was pioneered by Howard T. Odum in Environment, Power, and Society, Wiley, N.Y., 1971. For a general description of energy analysis and additional references, see: Martha W. Guillard, editor, Energy Analysis: A New Public Policy Tool (Boulder, Colorado: Westview Press, 1978).

<sup>116</sup>Robert Costanza and Robert Herendeen, "Embodied Energy and Economic Value in the United States Economy: 1963, 1967 and 1972," in Resources and Energy 6 (1984), pp. 129. (North Holland: Elsevier Science Publishers B.V.).

<sup>117</sup>Robert Costanza and Stephen C. Farber, "Theories and Methods of Valuation of Natural Systems: A Comparison of Willingness-to-Pay and Energy Analysis Based Approaches," Man, Environment, Space and Time, Vol. 4, No. 1, (Spring, 1984), p. 27.

<sup>118</sup>Robert Costanza and Stephen Farber, The Economic Value of Coastal Wetlands in Louisiana. Final Report to the Coastal Protection Section, Louisiana Department of Natural Resources, for the Project titled: "Benefits and Costs of Environmental Enhancement Projects in Louisiana". Louisiana State University, Baton Rouge, LA, pp. 26-31.

<sup>119</sup>*ibid*, p. 27.

<sup>120</sup>Henry M. Peskin, Letter in Science, Vol. 192, (April 2, 1976), p. 11.

<sup>121</sup>Robert Costanza and Stephen C. Farber, "Theories and Methods of Valuation of Natural Systems: A Comparison of Willingness-to-Pay and Energy Analysis Based Approaches," pp. 27-31.

<sup>122</sup>*ibid*, p. 29.

## **Chapter 6: Review of Disaggregated Environmental Accounting Frameworks**

### **1. Introduction**

The integration of environmental factors into concepts and measures of wealth and income requires specification of natural resource use and impacts, valuation of environmental capital, and a theoretical framework for inclusion of the net depletion of environmental capital into the economic accounts. Due to great difficulty in accomplishing these tasks, some analysts have abandoned the attempt to place all environmental factors in a monetary framework. Instead, they have concentrated on specification of natural resource use and pollution linked to the traditional accounts in a variety of ways. This chapter will survey these disaggregated approaches. In Sections 2 and 3, we review the French and Norwegian Natural Resource Accounts respectively. In Section 4, we examine Roefie Huetling's framework of environmental statistics, and we analyze Anthony Friend's proposal for Natural Resource Accounting in Section 5. In Section 6, the chapter summary, we consider the usefulness of these disaggregated proposals for the development of sustainable income measures.

### **2. The French Natural Resource Accounts**

In 1978, the French Commission on Natural Resource accounts requested an official statistical base for natural resources. The purpose of these accounts would be the provision of data to assess the available stock of natural resources, current use of these resources, and their qualitative condition (state of the environment).<sup>123</sup> There are three different valuation standards: economic, ecological, and sociocultural. Natural

resources are not included within the traditional economic accounts because the French believe that the valuation problems are too difficult.

The French classification of natural resources is based on subdivisions of the biosphere into hydrosphere, atmosphere, lithosphere, flora, and fauna.<sup>124</sup> The accounting units for measuring different natural resources are physical units, although the units may differ. Thus transformation units are needed at transition points if natural resources are to be aggregated across subdivisions.

The French accounting system has three separate accounts: the central, relational, and evaluation accounts. The relational accounts are detailed records of the use of important natural resources. They would track each natural resource from extraction through processing to final discharge of pollutants using simple material balance models. The central accounts are divided into natural resource accounts and agent accounts. The natural resource accounts record for each period and resource, the initial stock level, additions and subtractions in the period, and final stock level.<sup>125</sup> The natural resource accounts can be drawn up using different units for each resource depending on the aim. For example, the French suggest different accounting units for a forest depending on the aim considered. Economic purposes may require volume of timber, ecological purposes the numbers of species, while sociocultural purposes may require percentage of area accessible for hikers.

The agent account shows the effects on natural resources of economic and natural agents' activities. The agent account would reveal, for each resource, the causes of depletion or augmentation by agent. For example, some types of depletion or augmentation will be associated with households, firms, and government.

The evaluation accounts consist of two parts. First, the health index consists of a time series of quality indicators for each natural resource. For example, groundwater may be assessed in terms of inorganic content, vulnerability to contamination, etc. The second part of the evaluation accounts attempts to record ecological interactions

between natural resources. The French suggest that this 'account' consist of grids crossing natural resources against one another like an input-output table.<sup>126</sup> For example, in the case of water resources, these effects would be quantitative or qualitative changes in water due to interaction with other natural elements. This method appears to be a type of input-output ecological modeling rather than an account in the traditional sense. The monetary interactions among human economic agents are already quantified and valued in a conventional I/O table. The French evaluation 'accounts' are attempting to quantify, but not monetize, the interactions between nonmarketed environmental resources in an extended I/O framework.

The French accounts and indices provide a great deal of specification of the magnitudes and causes of changes in the stocks and flows of natural resources. However, they do not apply any aggregation to value the overall magnitude of changes in stocks and flows for all resources combined. The accounts are primarily descriptive and do not guide the inclusion or linking of natural resource data with the current monetary economic accounts. There is a danger that the natural resource accounts will not provide clear links between natural resource depletion and GNP due to three different valuation viewpoints, and the wide array of physical natural resource accounting units. Any attempts to assess environmental costs accompanying purely economic activity will be impressionistic and vague, unless all indices of environmental health move in the same direction. Such a situation may be rare, or, simply too late for remedial action.



### 3. Norway's Natural Resource Accounts

In 1978, the Central Bureau of Statistics of Norway was given responsibility for methodological development of natural resource accounts and preliminary studies on energy, land, and fish. The purpose of the resource accounts is to provide knowledge on quantities, qualities, and consumption of natural resources, and linkages between natural resources and macroeconomic development.<sup>127</sup> These goals are similar to those of the French accounts, but Norway only adopts the economic aim; other evaluation criteria are not explicitly recognized. The basis of Norway's accounts is the consideration of natural resources as capital. It uses the mass-balance framework for the stocks and flows of important materials and energy from the environment into economic goods and back to the environment as waste. The resource accounts are not fully integrated into the economic accounts because monetary valuation of natural resource reserves is considered too speculative for application.<sup>128</sup>

Norway's natural resource accounts require a classification of natural resources which is outlined in Table 6-1 below. Resources are first described as material or environmental resources, and then further classified according to physical characteristics.

TABLE 6-1: Classification of Natural Resources<sup>129</sup>

Economic classification	Physical classification
material resources	mineral resources: <ul style="list-style-type: none"> <li>- elements</li> <li>- minerals</li> <li>- hydrocarbons</li> <li>- stone, gravel, sand</li> </ul> <hr/> biological resources(life) <ul style="list-style-type: none"> <li>- in the air</li> <li>- in the water</li> <li>- on land and in ground</li> </ul> <hr/> inflowing resources <ul style="list-style-type: none"> <li>- solar radiation</li> <li>- the hydrological cycle</li> <li>- wind</li> <li>- ocean currents and waves</li> </ul>
environmental resources	status resources <ul style="list-style-type: none"> <li>- air</li> <li>- water</li> <li>- soil</li> <li>- space</li> </ul>

The Norwegian system consists of three basic accounts: natural capital including minerals and biological resources, material flow accounts, and environmental accounts (status resources such as air and water). The natural capital accounts record stocks of economically recoverable reserves in physical terms for important mineral resources and stocks of biological resources. For minerals and energy resources, balance sheets record initial reserves, new discoveries, revaluations, and extraction. The energy balance sheet records economical reserves, supplementary tables for hypothetical reserves, and calculations of the energy cost of all commodities. Energy is connected to GNP through specification of energy use for the sectors in the conventional economic

accounts.<sup>130</sup> For biological resources, balance sheets record initial stock, catch, natural growth and mortality, recruitment, and revaluations. In both cases, the revaluation is not monetary; rather, it encompasses new improved estimates of mineral or biological stocks. Although inflowing resources are recognized as a category of natural resources in Table 6-1, the only inflowing resource actually recorded in the present system is hydropower, which is included in the energy accounts.<sup>131</sup>

The material flow accounts follow important materials and energy from the natural state to the different sectors of the economy. These material balance accounts allow the calculation of the amounts of natural resources used and the wastes generated by different production sectors in the economy. The Norwegians use a simple material balance system because of problems of data collection, statistical interpretation, time, and money.<sup>132</sup> The accounts only include 'significant' flows of mass and energy which are directly influenced by human activity. Flows of material and energy within ecosystems and insignificant flows within the economic sphere are omitted. Extraction is linked to production through physically measured raw materials balances. Extraction of each raw material is distributed among geographical areas and production sectors, such as petroleum mining, fishing, etc. Emissions are linked to production through physically measured waste balances. Emissions of each waste product are distributed geographically and by production sector (including private households). The breakdown of extractions and emissions by geographic area is important because environmental effects may differ by area.

The environmental accounts consist of two parts: the emission accounts and the state accounts. The emission accounts record the emission of waste products into the air, water, and soil. The state accounts describe the state of the environment at different points in time and the changes of the environment in the periods between them. Much of the data for the environmental accounts comes from land and water basin registers

allowing identification of the geographical location of resource extraction or environmental stress.<sup>133</sup>

The resource accounts provide a great deal of information on the specification of the uses and environmental impacts of natural resources. In addition, they are able to show the direct and indirect resource uses of different sectors of the economic accounts. Their approach has a more direct connection to the economic accounts than the French multidimensional evaluation scheme. However, Norway's accounts do not directly make a monetary link between the depletion of marketable and nonmarketable environmental capital and the current economic accounting figures. However, except for the shadow values, the information is there to do so. The calculation of shadow values is recognized as an important research area in Norway, but they have not yet undertaken this task or the development of a theoretical framework for relating such shadow values to the traditional economic accounts. In an evaluation of their research program, the Norwegian Ministry of Environment considered the main problem to be the lack of success in exercising influence on traditional economic planning. Perhaps the main reason for this lack of influence is the lack of shadow values for marketable and nonmarketable natural resources.<sup>134</sup>

#### 4. Huetting's Framework for Environmental Statistics

Roefie Huetting's approach, explicitly based on economic theory, emphasizes nonmarketable natural resources.<sup>135</sup> According to Huetting, there is only an environmental problem if use of the environment creates an opportunity cost which is not explicitly considered in private decisions. For example, the use of water as dumping ground for waste may preclude the drinking and bathing functions of water for years to come.

Huetting divides the environment into the components of air, water, and soil. The environment performs functions for possible use by humans. Whenever one function is utilized by humans at the expense of others, a choice has to be made between competing functions. There are three types of competition among functions: quantitative, spatial, and qualitative. Quantitative competition occurs when there is not enough of an environmental component for its intended uses; examples are water for agriculture versus water for recreation versus water for industrial uses. Spatial competition occurs when there is not enough space for the use of several functions; examples are land in cities for highways, biking, and walking. Although Huetting separates quantitative and spatial competition, one could consider spatial competition as a subset of quantitative competition. Qualitative competition occurs when humans introduce substances into the environment which may qualitatively change that environment and cause losses of other functions.

Losses of function due to spatial or quantitative competition are recorded in statistical tables. The functions are arrayed by columns and rows, while the losses of function are placed in the cells of the tables. Since the functions compete directly, the tables reveal what functions have foreclosed others. For example, the irrigation function of water for agriculture may have precluded the recreation function of water. This information is a necessary condition for determining the costs of losses of functions.

Losses of function due to qualitative competition involve an intermediate stage rather than direct competition. Human activity introduces agents to the environment which cause losses of function. A substance may cause loss of function either by its addition to or its withdrawal from the environment by humans (heat, chemicals, radioactivity, etc.). There are two sets of tables which record environmental statistics describing qualitative competition. The first set of tables matches agents with their originators. The agents are subdivided into biological, chemical, and physical categories, and they are classified in accordance with their action in water, air, and soil.

For example, agriculture may introduce organic poisons into water and soil.<sup>136</sup> The second set of tables relates the agents with different environmental functions to reveal the losses of functions due to the agents.<sup>137</sup> For example, the introduction of organic poisons into water and soil may lead to losses of drinking water functions through poisoning of groundwater. Once the human activities, agents, and losses of functions have been specified, analysts can match activities with agents which caused losses of environmental functions. This matching is a necessary condition for determining costs of losses of function.<sup>138</sup>

The above framework is linked to economic activity in that it matches originators of destructive agents with environmental deterioration and direct competition among different environmental uses. However, Huetling does not attempt to quantify cases where uses of environmental functions are complementary. For example, an oil platform uses water for oil production, but it may also create new fishing habitat. Whether environmental gains or losses are considered, a monetary linking of the losses or gains of environmental functions with the production of conventional economic goods requires the construction of shadow prices for nonmarketed environmental functions. Such a shadow price requires knowledge of the supply and demand for environmental functions. Huetling does not believe it is possible to provide accurate environmental shadow prices in most circumstances. In particular, the demand curve for environmental functions is very difficult to determine for reasons stated in the critique of Peskin in chapter 5.<sup>139</sup> Since shadow prices cannot usually be constructed for environmental functions, Huetling advises that we directly weigh the utility of environmental functions needed for production and consumption of market goods (water as dumping ground for waste) with the utility of other environmental functions disturbed by these activities (water for drinking). The utility of environmental functions used in production and consumption of market goods can be derived from the utility of the market goods. However, the utility of the nonmarket environmental functions disturbed by production can only be derived

from a description of the activities that utilize them (drinking water, etc.). For example, if a chemical plants' production is destroying groundwater for drinking, then we need to compare the utility of the chemical products involved to the lowest of the three opportunity costs: utility of drinking water loss, the costs of cleaning up the water, or of adopting cleaner production processes. What we lack in this comparison is a reliable monetary estimate of the present and future demand for groundwater.

Huetting recommends two accounts which could supplement the traditional economic accounts rather than replace them. The first requires a differentiation of environmental expenditures in the economic accounts. Examples are expenditures to reduce environmental stress, remove waste and other pollutants, and repair damage to health. These expenditures would be interpreted as intermediate rather than final goods. The isolation of environment related expenditures in GNP would make possible an awareness of the extent to which environmental stress and damage have produced economic reactions. Unremedied environmental degradation would not be considered.

Huetting's second supplementary account links environmental degradation to income measures using environmental standards.<sup>140</sup> Although he maintains that it is impossible to completely value environmental goods and thus net depletion, a second best approximation to a depletion allowance is to compute expenditures required to meet government environmental standards. For example, the standard could be based on requirements for sustainable development. It would in principle be possible to estimate the dollars required to meet government standards, wherever human production and consumption has rendered environmental quality below the standards. The total cost of meeting the environmental standards will then be an expression of how far the nation has deviated from its environmental standard. This total cost is a proxy for a capital consumption allowance. If environmental quality is reduced further below the standard over several years, then the total costs of meeting the standard rise, indicating a greater loss of environmental capital.

Huetting's system does not directly consider marketable natural resources; however, it provides detailed specification of the impacts of the production and consumption of conventional economic goods on nonmarketable environmental capital. Huetting goes further than the French and Norwegian systems in attempting to value the losses of environmental functions. In theory, Huetting would consider human expenditures on repair of environmental functions as intermediate goods and thus subtract them from measures of sustainable income. Since, in practice, he regards accurate monetary valuation to be impossible for most environmental functions, Huetting's system does not provide a complete monetary valuation of net depletion of environmental capital for use in the economic accounts. However, his two supplementary accounts do provide a direct monetary linking of environmental degradation to current GNP measures.

#### 5. Friend's Natural Resource Accounting Framework

Anthony Friend's proposal for Natural Resource Accounting (NRA) provides one of the most thorough complements to the current economic accounts.<sup>141</sup> The proposed NRA would be a natural resource database which describes the stocks and flows of natural resources; establishes linkages between natural resources, economic production and pollution; and evaluates the status of environmental services. According to Friend, the purpose of NRA would be to identify and record the variables which assess the capacity of the natural resource base to maintain sustainable economic development. The basis of Friend's accounting system is the recognition that human economic activity takes place in natural systems characterized by ecological interdependence and constrained by thermodynamic laws.

The NRA accounting framework consists of four accounts: First, the Resource Stock Account records balances of stocks of natural resources. Resources are divided



into biological resources such as fisheries, non-renewable resources such as fossil fuels, and cycling systems such as the hydrosphere. Second, the Stock Accretion and Depletion Account records net depletion of resource stocks. Third, the Resource Sector Account records the flow of resources to the economy using the material energy balance system. Finally, the Resource Status Account links resource use and production with the state of environmental services.

The Resource Status Account linkage is complicated. It utilizes the Stress-Response Environmental Statistical System (STRESS) to link economic activities and environmental changes. The rationale for STRESS is the integration of macro-activities (stressor activities) with responses particular to each ecological zone. STRESS uses ecological mapping to divide the country up into biomes and their ecosystem subcomponents. It then attempts to record the state of these micro environments and their rate of change relative to some standard and to identify the sources of and response to stress. This information warns policymakers of actual or impending environmental quality deterioration, particularly irreversible losses.

The framework of STRESS consists of three primary data sets.<sup>142</sup> First, state of the environment data measure both elements that place stress on the environment (emission of pollutants) and environmental responses to these stresses (increase in pollution loadings). Second, activities data measure stressors, or human and natural activities that have the potential to degrade the environment. Activities data also measure the policy response of humans to environmental degradation. For example, both the generation of waste residuals and the response of increased abatement expenditures would be placed in the activities data set. Some of Friend's response measures such as abatement expenditures are in dollars. Although Friend does not specifically recommend aggregating response measures in dollars, it is possible to aggregate some of these responses to environmental problems and compare them to GNP changes. Third, stock data have information on the stocks of renewable and

nonrenewable natural resources. Although some of the response data (costs) are in dollars, STRESS does not monetize the baseline value of the environment nor changes in the environment over time.

Statistics Canada carried out a case study of STRESS for the Laurentian Lower Great Lakes from 1978-1981.<sup>143</sup> The study was limited to the assessment of qualitative changes in the Great Lakes from an ecological health standpoint, omitting environmental impacts on human health, and qualitative and quantitative assessments of marketed natural resources in the watershed. Stress data were readily available, but response data were more rudimentary. It appears that STRESS would be a very expensive system to implement even in the richest industrial countries. However, such a system may be necessary if humans continue to stress the environment within proximity of the limits of the capacity of natural systems.

Friend's NRA account provides a detailed specification of natural resource use and environmental impacts. However, it does not value the natural resources in monetary terms. Friend does not wish to include the NRA directly within the economic accounts for two reasons. First, the primary focus of the national economic accounts on market activity may result in too much attention paid to marketed natural resources rather than other very important nonmarketed resources. Second, the conversion of natural assets to monetary equivalents might be restrictive in defining the nature and scope of resource accounting.<sup>144</sup> Hence his system does not provide a monetary link between environmental degradation and GNP. There is no theoretical basis for the environmental standards necessary to implement the STRESS measures. Risk aversion may suggest that under uncertainty and high costs of errors in valuation, the maintenance of environmental capital through physical environmental standards is justified, although the level of the standard is debatable. Friend's NRA system is also highly disaggregated so that ecological zone-specific responses can be measured. However, some aggregation of his system for the organization and presentation of environmental data at the macro-

level would be useful. Then environmental change could be more easily compared to current aggregate economic measures such as GNP. Friend recognizes this as he calls for the establishment of public reporting systems based on a small number of resource and environmental indicators.

## 6. Summary

We have surveyed four approaches to accounting for natural resources. All frameworks produce physical specification of baseline resource conditions and environmental changes linked in some way to economic activity. However, there is a large variation in the manner in which environmental information is presented to policymakers, and the extent to which the environmental accounts can be compared to traditional economic accounts.

The French system requires the most detailed specification of natural resource use and environmental impacts due to the three valuation viewpoints. It does not yield a few aggregate physical or monetary environmental indicators. There is no method of making tradeoffs between different valuation viewpoints, nor between changes in different environmental parameters within one viewpoint such as economic. Hence their system is not useful for comparing changes in environmental capital with GNP.

The Norwegian system requires less data because of one valuation viewpoint and the elimination of flows of material and energy within ecosystems from the MEB framework. Norway also physically aggregates some resource categories in the MEB system. The MEB component allows policymakers to compare projected GNP increases with uses of important marketed natural resources. Norway's Resource Accounts have less data to confuse the policymaker, but there is still no small number of physical indicators which can be used as proxies for physical environmental capital depreciation, and no attempt at monetization of resource values is made. However, if the

environmental changes are physically aggregated to narrow down the mass of data, then the necessary material is there for policymakers to assign shadow values and make tradeoffs.

Huetting's system is limited to the specification of nonmarketed natural resources. His environmental accounts allow a physical comparison of environmental degradation and particular economic activities so we know what the physical tradeoffs are. His supplementary account of environmental expenditures can be compared to GNP over time in order to determine the percentage of GNP that is for remedied degradation of environmental capital. Huetting's proposal to construct a dollar figure of the costs of meeting government environmental standards allows policymakers to compare increases in traditional economic accounts with the distance from environmental standards. Although this proposal requires specification of environmental quality and dollar estimates of costs of meeting standards, it is the best feasible method of linking environmental capital depreciation with macroeconomic income measures of the four approaches.

Friend's system requires a large amount of environmental statistics in addition to resource stock accounts and material energy balance accounts. However, the STRESS framework is conceptually well organized; much diverse, existing environmental data can be fitted into it. Friend's system requires some physical aggregation to limit the choice of tradeoffs for policymakers to a feasible set. STRESS is similar to a more detailed version of Huetting's framework of environmental functions and remedial expenditures. Although neither Friend nor Huetting place dollar values on environmental assets, some response measures in the STRESS account can be monetized. Thus there is potential in STRESS to devise an indicator of dollar cost distance from standards such as the one which Huetting recommends.

123 Jacques Theys, "Natural Resource Accounts: French Experience and the Case of Water Resources," Ad hoc Expert Consultative Meeting on Environmental Accounting and Its Use in Development Policy and Planning (Geneva, United Nations Environment Program, 1983), p. i.

124 *Ibid.*, p. 2.

125 *Ibid.*, p. 11.

126 *Ibid.*, p. 32.

127 Arild Garnasjordet and Petter Longva, "A System of Resource Accounts: The Norwegian Experience," Ad hoc Expert Consultative Meeting on Environmental Accounting and Its Use in Development Policy and Planning (Geneva: United Nations Environment Program, 1983), p. 1.

128 *Ibid.*, p. 6.

129 Per Arild Garnasjordet, "Resource Accounts of Norway," Ad hoc Expert Consultative Meeting on Environmental Accounting and Its Use in Development Policy and Planning (Geneva, United Nations Environment Program, 1983), p. 3.

130 "A System of Resource Accounts: the Norwegian Experience", p. 25.

131 Knut H. Alfsen, Torstein Bye, and Lorents Lorentsen, "Natural Resource Accounting and Analysis: The Norwegian Experience 1978-1986," (Oslo: Kongsvinger. Statistisk Sentralbyrå, 1987), p. 16.

132 "A System of Resource Accounts: The Norwegian Experience", p. 8.

133 *Ibid.*, p. 18.

134 "Natural Resource Accounting and Analysis: The Norwegian Experience 1978-1986", p. 46. The Natural Resource Accounts in Norway are a joint responsibility of the Ministry of Environment and the Central Bureau of Statistics.

135 Roefie Huetting, "The Use of Environmental Data in the Economic Decision-Making Process: Contribution of the Netherlands Bureau of Statistics" Ad hoc Expert Consultative Meeting on Environmental Accounting and Its Use in Development Policy and Planning (Geneva: United Nations Environment Program, 1983).

136 *Ibid.*, p. 6.

137 *Ibid.*, p. 7.

138 Tables for water and air have been developed by the Netherlands Central Bureau of Statistics for that country. For examples, see Appendix I of Roefie Huetting, New Scarcity and Economic Growth: More Welfare through Less Production? (Amsterdam: North-Holland Publishing Co., 1980), pp. 191-229.

139 The reasons given for difficulty in determining shadow prices were: (1) difficulty in specifying the physical environmental impacts of human production of conventional goods. (2) lags between the environmental effect and the effect on human health and ecosystems. (3) even if the physical environmental effects and interrelations are specified, it is difficult to value beforehand the expected damage costs from pollution because of ignorance of the true value of environmental functions.

140 Roefie Huetting, in cooperation with Nizam A. Yunus, "A Note on the Construction of an Environmental Indicator in Monetary Terms as a Supplement to National Income With the Aid of Basic Environmental Statistics," Jakarta, March 22, 1986. Note was presented to Workshop 4 of the UNEP-World Bank Working Group Meeting on National Accounting for the Environment, Washington, D.C., November 17-18, 1986. This second

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method was used in consultation with the Indonesian government. Although a complete study of the cost of meeting various environmental standards was not carried out, Huefing did present the methodology and tables needed to construct the costs of a standard for soil erosion in Indonesia.

<sup>141</sup>Anthony Friend, "Discussion Paper on Natural Resource Accounting and its Relationship with Economic and Environmental Accounting," September, 1986, Ottawa, Ontario.

<sup>142</sup>D. Rapport and A. Friend, "Towards a Comprehensive Framework for Environmental Statistics: A Stress-Response Approach," Statistics Canada, Ottawa, 1979.

<sup>143</sup>D. F. Rapport, "A Case Study of the Stress-Response Environmental Statistical System: The Laurentian Lower Great Lakes" (Working Paper No. 2), CES/SAEP, Informal Meeting on Frameworks for Environmental Statistics, Geneva, 1981.

<sup>144</sup>"Discussion Paper on Natural Resource Accounting and its Relationship with Economic and Environmental Accounting", p. 2.

## **Chapter 7: Capital Consumption Allowance for Louisiana Wetlands**

### **1. Introduction**

The coastal wetlands of Louisiana contain approximately 25% of the contiguous US coastal wetlands.<sup>145</sup> They provide many important services such as living area for over 1,000,000 people, protection of urban areas such as New Orleans from hurricanes, spawning areas for Louisiana's fishing industry, and recreation. Oil and gas are very important marketable natural resources which have been discovered in abundance beneath the Louisiana Coastal Zone and offshore in areas of the Gulf of Mexico owned by the Federal government. There were more than 28,000 oil or gas wells in operation in the Louisiana coastal zone in 1981.<sup>146</sup> Furthermore, oil and gas wells operating in the Federal Outer Continental Shelf zone use pipeline canals in the Louisiana Coastal Zone for transporting oil inland; and also use access canals for servicing rigs. More than 70% of the oil and 90% of the gas from all US Coastal waters comes through pipeline and navigation canals in the Louisiana Coastal Zone.<sup>147</sup>

Louisiana's wetlands have deteriorated rapidly in recent decades, and available data indicate a trend of exponential loss at the present time. Approximately 60 square miles of Louisiana wetlands were lost in 1986 alone.<sup>148</sup> Oil and gas production has been implicated as an important cause of the recent rates of wetland loss.

This chapter will attempt to derive this wetland/oil tradeoff as precisely as current data and methodology will allow. In Section 2, we consider why oil and gas production is an important cause of wetland loss. In Sections 3 and 4, we use two different methodologies to estimate wetland damage functions due to oil and gas. In Section 3, we use a team of ecologists' consensus estimates of the percentage of Louisiana wetland loss due to oil and gas activity over a 24 year period to determine two average wetland loss functions due to oil and gas for 1986. The first yields the average loss in

acres per thousand barrels of oil-gas equivalent, while the second yields the average loss in acres per well. These average damage functions only require an estimate of total oil and gas induced wetland loss and a measure of total oil and gas activity over a given time period. They do not require annual data on wetland loss and oil and gas activity. However, due to the lack of annual data, the average damage functions cannot be used to determine the marginal wetland loss due to a unit of oil and gas activity in a given year. Since the marginal wetland loss may be very different from the average loss over a long period, the average damage function may yield inaccurate annual estimates of wetland loss. In addition, the two average damage functions are based on arguable consensus estimates rather than one statistical model. In Section 4, we estimate marginal wetland loss functions due to oil and gas by a time series statistical approach which does not rely on any apriori estimates of the range of wetland loss due to oil and gas. The estimation of marginal wetland loss functions requires annual data on wetland loss and oil and gas activity for the period 1955-86. Three different annual wetland loss functions are derived from four annual measurements. Two different proxies for the environmental impact of oil and gas activity are used: (1) annual oil and gas production in barrels (2) annual oil, gas, and dry wells completed. For each of the three wetland loss functions, we derive two marginal loss functions of wetlands due to oil and gas activity: one using production and the other wells. These loss functions yield the marginal wetland loss due to one more unit of oil and gas activity in a given year rather than the average loss over the entire 32 year period. In Section 5, we construct capital consumption allowances for each oil and gas induced loss function of wetlands from Sections 3 and 4 by using the economic values of nonmarketed wetland services from other studies. We summarize this chapter's findings in Section 6.



## 2. Oil and Gas Activity and Wetland Loss

Current oil and gas production causes wetland loss in both current and future time periods. The major immediate causes of wetland loss are the initial construction of well sites and access canals. Although any one well site may involve only a small amount of wetland loss, there are thousands of wells in the Louisiana Coastal Zone. In addition to the conversion of some wetland area to building and storage sites, etc., well sites in the Coastal Zone involve wetland destruction due to the surface discharge of oil field brine and oil and gas drilling waste discharges. The high salinity and other contaminants in these wastes may destroy habitat in the vicinity of the well which leads to wetland erosion. However, the major immediate costs of oil and gas production are canal construction rather than the area used for well sites. If only private costs are considered, canal dredging is the cheapest method of creating access to and from the many oil sites in the wetlands. Much immediate wetland loss occurs due to the dredging of oil rig access canals, pipeline canals, and deep-draft navigation channels for oil industry support vessels. Canals and spoil banks, the material excavated by canal dredging, now occupy approximately 7% of the coastal surface area.<sup>149</sup>

The greater part of wetland loss due to current oil and gas production may occur in future time periods due principally to delayed environmental effects of the introduction of canals. Virtually all canals widen over time depending on boat traffic, age, and substrate characteristics.<sup>150</sup> In one recent study of 3 old coastal Louisiana canal systems, canals in areas of greatest boat activity widened at a rate of 2.58 meters/year, while those in areas of minimal boat activity widened at a rate of .95 meters/year.<sup>151</sup>

Most wetland loss over time due to canals and associated spoil banks occurs through alteration of hydrologic regimes rather than canal widening.<sup>152</sup> Canals dredged in alignment with prevailing marsh water flow tend to lessen freshwater retention time and allow greater inland penetration of saltwater. The increased salinization and

waterlogging may kill some dominant plant species in the marsh. For example, *spartina patens*, the dominant species of brackish marshes, is sensitive to increased soil waterlogging and increased salinity.<sup>153</sup> The destruction of marsh plants reduces sediment accumulation by the marsh and thus hastens the conversion of marsh to open water. Spoil banks and canals dredged transverse to natural water flow tend to impound water. The cumulative impact of many small canals is often the unintentional impoundment of marshes. This interruption of hydrologic flows to and from the impounded area leads to decreased sedimentation rates, subsidence, and eventual conversion of many canalized areas to open water. In one study of Louisiana marsh areas intentionally impounded approximately 70 years ago, 82 percent of areas impounded before 1915 and not currently used for agriculture, urban areas, or navigation channels had become partially or wholly open water habitat.<sup>154</sup> The above evidence indicates that oil and gas production has significant immediate and delayed effects on wetland loss.

Oil and gas production is not the only significant cause of Louisiana wetland loss. Some of the most important other causes may be the use of the Mississippi river for navigation and flood control rather than wetland building, general development in the wetlands (roads, houses, industrial buildings, farms), sea level rise, and natural subsidence of old river deltas.<sup>155</sup> Although there is no certain information on the exact causes of wetland loss, it is doubtful that the latter two influences are important contributors to the recent rapid increase in wetland loss. The past record does not indicate exponential land loss rates even for old deltas. Although sea level rise due to worldwide fossil fuel combustion may have profound consequences for future wetland loss, it is unlikely that this phenomenon was an important causal factor in the 1955-86 period. Recent wetland loss in Louisiana is primarily due to wetland subsidence (which itself has a number of causes such as canals, reduction of river sediments to wetlands, etc.) rather than sea level rise.<sup>156</sup>

Perhaps the most important cause of wetland loss other than oil and gas production for the 1955-86 time period is the diversion of Mississippi river sediments from the wetlands to the Gulf of Mexico.<sup>157</sup> The leveeing of the Mississippi river since the 1930's has severely restricted the supply of wetland sediments through overland flooding in the Spring. Furthermore, the Mississippi river cannot build new wetlands at its mouth due to the extension of the current delta out to near the very deep waters at the edge of the continental shelf. The diversion of Mississippi river sediments away from the wetlands may have complementary effects on oil and gas induced wetland loss. It is conceivable, in principle, that if it were not for existing river diversion policies, oil and gas activity would have caused no net loss of wetlands. The existence of other significant causes of wetland loss has important consequences for the statistical estimation of our marginal wetland loss functions due to oil and gas in Section 4.

### 3. Average Wetland Damage Function

The most recent comprehensive study (Turner-Cahoon) of the causes of wetland loss in Louisiana attributed 30-59% of the total wetland loss from 1955-1978 to oil and gas production in the Federal Outer Continental Shelf (OCS) and Louisiana Coastal Zone.<sup>158</sup> The 30-59% range is a consensus estimate of these ecologists based on the results of their own study and many other studies of ecological interactions in the wetlands rather than a precise numerical result of one general ecological model. In addition, the range is a coastwide estimate rather than an accurate predictor of the loss range in small local wetland areas with different conditions from the 'average'. Using this consensus estimate, we compute the range of wetland loss due to oil and gas activity from 1955-1986 in Table 7-1 below. We assume that the range of oil and gas induced wetland loss from the 1955-1978 Turner-Cahoon study is the same for this extension to the 1955-1986 period. The low and high ranges of wetland loss given in

Table 7-1 were calculated by multiplying the total wetland loss by the Turner-Cahoon percentage of loss due to OCS, Coastal Zone, and OCS plus Coastal Zone oil and gas activity. For example, the total wetland loss from 1955 to 1986 was 799,403 acres. Thus the 30 to 59% range of OCS plus Coastal wetland loss is 239,821 to 471,648 acres. In Table 7-1, we compare the range of wetland loss due to oil and gas, cumulative oil/gas production, cumulative oil, gas, and dry wells completed, average wetland loss in acres per thousand barrels of oil equivalent, and average wetland loss per well for the 1955-86 period.

Table 7-1: Louisiana Wetland Loss due to Oil & Gas Activity, 1955-1986<sup>159</sup>

	<u>OCS (thou bbl)</u>	<u>Coastal</u>	<u>OCS + Coastal</u>
Production	18,697,519	19,282,984	37,980,503
Wells completed	171,639	26,431	198,070
Wetland Loss Low	63,952 (acres)	175,869	239,821
High	135,899	335,749	471,648
Loss/thou bbl Low	.0034 (ac/thou bbl)	.0091	.0063
High	.0073	.0174	.0124
Loss/well Low	.3726 (ac/well)	6.6539	1.2108
High	.7918	12.7028	2.3812

The data in Table 7-1 yields the total and average wetland loss per thousand barrels and per well over the 1955-1986 period. For example, the extraction of one thousand barrels of total oil/gas over the 1955-86 period destroyed .0063 to .0124 acres of wetlands. One well completion destroyed 1.2108 to 2.3812 acres of wetlands over the same period.

We can derive two average wetland loss estimates, one based on oil/gas production, the other on wells completed. If we take the low estimate of wetland loss per

thousand barrels, then an average wetland loss estimate for year t based on oilgas production is given by equation (1) below:

$$(1) \quad WL_{O\&G} = .0063 * (O_t)$$

where:

$WL_{O\&G}$  = wetland loss in year t due to oil and gas activity in year t

$O_t$  = OCS and Coastal oilgas production in year t in thousands of barrels

An average wetland loss function for 1986 using well completions for the low estimate of wetland loss per well of 1.2108 acres over the 1955-86 period is given by equation (2) below:

$$(2) \quad WL_{O\&G} = 1.2108 * (O_t)$$

where:

$WL_{O\&G}$  = wetland loss in year t due to oil and gas activity in year t

$O_t$  = OCS and Coastal oilgas and dry wells completed in year t

Table 7-2 below presents the oil and gas related wetland loss in each year according to equations (1) and (2) above. .

Table 7-2: Annual Wetland Losses due to OCS+Coastal Oil &amp; Gas Activity (low range)

<u>Year</u>	<u>Acres Lost (Prod)</u>	<u>Acres Lost (Wells)</u>
1955	1628	1645
1956	1950	1665
1957	1283	2031
1958	2358	2303
1959	2898	3579
1960	3463	4254
1961	3792	4934
1962	4779	5726
1963	5170	6255
1964	5561	7000
1965	6221	7024
1966	7571	5107
1967	8858	5443
1968	9989	6158
1969	10942	6277
1970	12053	6986
1971	12576	7260
1972	12326	7502
1973	11650	7988
1974	11014	7695
1975	9972	7494
1976	9495	7875
1977	9372	9477
1978	9597	9876
1979	9299	10496
1980	8686	11070
1981	11621	11736
1982	7970	12431
1983	7157	13040
1984	7777	12952
1985	7417	13299
1986	6973	13245

The average oil and gas induced wetland loss for 1986 using production data is 6,973 acres, while the average loss using well data is 13,245 acres. These estimates are our first proxies for a 1986 wetland loss function due to oil and gas activity.

The average historical wetland loss over these two periods reflects the total loss from oil and gas production. However, an average loss in any given year is inaccurate to

the extent that the marginal loss (annual) differs from the average loss over the time period. For example, the loss figures based on annual oil and gas production in Table 7-2 indicates that annual wetland loss peaked in 1971 and then declined because the average loss assumes that oil/gas production in years  $t-1$ ,  $t-2$ , etc., is independent of wetland losses in year  $t$ . Using equation (1), as soon as current oil production falls, wetland loss rates fall. However, this relation may not hold. Current wetland losses could increase even when current oil production is declining if past oil production has lagged effects on future wetland loss. As we noted in Section 2, there are significant delayed environmental effects of oil and gas production. Hence it is useful to attempt to determine a wetland loss function which takes into account marginal losses in a given year. This is the task of Section 4.

#### 4. Marginal Wetland Damage Functions

There are two problems with the method of determining an oil and gas induced wetland loss estimate in Section 3. First, it is based on arguable consensus estimates rather than a statistical model. Second, it only allows calculation of the average loss although evidence on lagged environmental effects of oil and gas production suggests that the marginal wetland loss may be significantly different from the average observed wetland loss over the period. The average loss is a ratio of total oil and gas induced wetland loss over a measure of total oil and gas activity in the period. It does not yield any direct information on the annual changes in oil and gas induced wetland loss over the period. However, these marginal changes will be different from the average except in the unlikely case where the marginal wetland loss is the same in every year. A loss function based on marginal loss may be more accurate than one based on average loss. In this section, we will attempt to calculate marginal capital loss functions using a simple statistical model. An annual (marginal) loss function which allows for lagged effects of oil

and gas production on wetland loss requires time series on annual wetland loss, oil and gas activity, and all other significant causes of wetland loss. Such a statistical model would be of the form:

$$(3) \quad WL^T = [\text{Intercept}, X, X_{t-1}, X_{t-2}, \dots, O_t, O_{t-1}, O_{t-2}, \dots] + e_t$$

where:

$X_t$  = important causes of wetland loss in year  $t$  other than current or past oil and gas activity

$WL^T$  = total wetland loss in year  $t$

$O_t$  = total oilgas activity in year  $t$ . (measured as total oil and gas production in thousands of bbls or as total oil and gas wells drilled)

$e_t$  = error term representing unsystematic causes of wetland loss

Given this model, the marginal wetland loss in year  $t$  due to oil and gas activity could be predicted from the coefficients of the independent variables. However, we cannot estimate the complete wetland loss model in equation (3) due to several data limitations. First, annual wetland loss data are not available for even a small area of the Louisiana wetlands. The Turner-Cahoon study compared wetland loss in quadrants only for 1955 and 1978 due to the lack of annual wetland loss data. Therefore, we will create a pseudo annual wetland loss time series from four annual wetland loss data points in the 1955-86 period using linear interpolation, linear regression, and an exponential function. Table 7-3 below contains the four estimates of annual Louisiana wetland loss in recent years which were used to construct our pseudo annual wetland loss functions.



Table 7-3: Annual Estimates of Louisiana Wetland Loss

<u>Year</u>	<u>Annual Loss (sq mi)</u>	<u>Annual Loss (acres)</u>	<u>Source</u>
1955	21	13,440	Gagliano, 1970 <sup>160</sup>
1967	35	22,400	Gagliano, 1981 <sup>161</sup>
1980	50	32,000	Gagliano, 1981
1986	60	38,400	Templet, 1986 <sup>162</sup>

The three pseudo loss functions created from the data in Table 7-3 yield the dependent variable in the regressions which analyze causes of wetland loss. The construction of the dependent variable implies construction of the error term. The errors from a wetland/oil regression with our pseudo data will probably be smoother than the errors from actual wetland loss data which would not exactly follow an assumed functional form such as linear or exponential. Hence, we cannot be sure of the true distribution of our statistics, and our R-squared values may be higher than would be the case with real data. However, these problems are not significantly different from those associated with the widespread use of pretest estimators with unknown statistical properties in econometric work. We have attempted to meet this problem to some extent by choosing three different wetland loss functions (linear interpolation, linear regression, and exponential) based on the four annual data points. If the different forms yield similar results, then we will have more confidence that the final wetland loss/oil and gas activity relation is not just an artifact of a chosen annual wetland loss functional form such as exponential regression. Since much discussion on the wetland loss problem assumes an exponential trend based on a few data points, our construction of wetland loss functions does have the advantage of making the choice of wetland loss functional form explicit.

The second statistical problem involves uncertainty as to the best available proxy for the environmental effects of oil and gas activity on wetlands. We have chosen two

proxies for this environmental effect: annual oil and gas production in the Louisiana Coastal Zone and the Federal Offshore region (OCS), and annual oil, gas, and dry wells completed in both the Coastal Zone and OCS region. Dry wells are included in our well total because their environmental impact is significant even though they do not contribute to oil or gas production. The well data may yield a better measure of the environmental impact of oil and gas extraction than the production data. Annual canal data, another possible proxy, are not available. The possibility of error in the choice of the best measure of environmental effects of oil and gas production is a specific example of a very common problem in econometric work. We are never sure if our variables are the best measures of the phenomenon we wish to study.

The third and most serious statistical problem in our estimation process is the lack of annual data on important causes of wetland loss other than oil and gas activity. Other significant independent variables are omitted. In particular, there is no proxy for the diversion of Mississippi river sediments from the wetlands to the Gulf of Mexico although it is recognized as a very important cause of Louisiana wetland loss.<sup>163</sup> If this omitted variable is correlated with oil and gas activity, then our ordinary least squares estimates (of the effect of oilgas activity on wetland loss) will be biased, and the error variance will be biased upward. If the omitted variable has a positive impact on wetland loss, then the ordinary least squares procedure will incorrectly attribute some of the causal effect of sediment diversion to oil and gas production.<sup>164</sup> Hence our estimates of wetland loss due to oilgas production will be high relative to a correct model which included all relevant variables. Since our simple model in all likelihood excludes some important independent variables for which no data are currently available, the omitted variable problem is a liability of our statistical approach. The simplifications we have introduced mean that our model will be of the form shown below in equation (4):

$$(4) \quad WL^T = [\text{Intercept}, Ot, Ot-1, Ot-2, \dots] + et$$

where:

WL<sub>T</sub> = total wetland loss in year t

O<sub>t</sub> = total oil/gas activity in year t. (measured as total oil and gas production in thousands of bbls or as total oil and gas wells completed)

e<sub>t</sub> = error term representing unsystematic causes of wetland loss

The first step in estimating (4) is the construction of our three pseudo wetland loss functions from the four annual wetland loss data points in Table 7-3. Our first wetland loss function is a simple linear interpolation between these four data points, derived by assuming a linear relation between each of the points. For example, annual wetland loss between 1955 and 1967 was derived by determining total increase in annual wetland loss of 8,960 = (22,400 - 13,440). This total increase was divided by 12 to determine the additional wetland loss each year.

Our second pseudo wetland loss function uses simple linear regression of wetland loss on time (years) to generate the following equation.

$$(5) \quad WL_T = -30,280 + [789 * t]$$

Our third annual pseudo wetland loss function uses exponential regression of wetland loss on time (years) to generate the following equation:

$$(6) \quad WL_T = 2251 * 10^{(.0144 * t)}$$

Note that the 1.44% growth rate of wetland loss in equation (6) is based on four annual measurements of wetland loss over the 1955-86 period. This method is different from the Turner-Cahoon study which estimated a 0.86% rate based on the total wetland loss over the 1955-78 period.<sup>165</sup> The three different 1955-1986 data series formed through linear interpolation, linear regression, and exponential regression are placed in Table 7A-5 in the Appendix to this chapter.

Our three wetland loss functions will now be used separately as dependent variables in regressions of wetland loss on oil and gas activity. Coastal Zone and OCS annual oil and gas production and oil and gas wells completed will be used separately

as independent variables in these regressions. Hence there are six equations to estimate. For each of the three wetland loss functions (dependent variable), we estimate two equations corresponding to the independent variables of oil and gas production and oil and gas wells, respectively.

Once the data and the simple model in equation (4) above were chosen, the next step was the determination of the lag length. The basic choice is between finite and infinite lag models. Although we eventually chose the infinite lag model described below, we first tried and rejected a finite lag model. We will briefly survey the procedures used in the testing of the finite lag model here; a detailed treatment is provided in the Appendix to this chapter. Due to limited degrees of freedom with only 32 total observations, the maximum lag length considered was nine. Durbin-Watson statistics for this nine lag model indicated the presence of positive first order autocorrelation in all six equations. After correction for autocorrelation, we used a pretesting procedure to determine the lag length. Starting with nine lags, we dropped a lagged value if the *t*-statistic was not significant at 5 percent. This process resulted in a variety of lag lengths from four to nine for the six equations. Once the lag length was determined for each of the six models, we fitted an Almon polynomial lag to the data using a conventional *F* test with restricted (the coefficient of the highest polynomial degree is zero) and unrestricted models. If the *F* value was not significant at 5%, we accepted the hypothesis that the highest polynomial degree was zero. This process resulted in a first degree polynomial (form  $a + bx$ ) for all equations. However, the coefficient on the last lag length for all models was positive and higher than the other lag coefficients. This indicates that oil and gas related wetland loss increases for 4 to 9 years (length of the lag according to the *t*-statistic pretesting procedure) and then suddenly drops to zero. This is not a plausible scenario for oil and gas induced wetland loss; it may mean that the effects of oil and gas activity are spread out over a far longer time period (e.g., decades) than our finite lag model of 32 observations can handle.

A more plausible model of oil and gas related wetland loss may indicate a steady decline over a very long time period in the negative environmental impact of oil and gas activity in an earlier year. Hence we decided to approximate equation (4) with an infinite lag model.

A popular form of an infinite lag model which may describe oil related wetland loss is the geometric lag. It has the form of equation (7) below:

$$(7) \quad WL^T = a + b [O_t + cO_{t-1} + c^2O_{t-2} + c^3O_{t-3} \dots] + e_t$$

where:

$WL^T$  = total wetland loss in year t

$O_t$  = total oil/gas activity in year t. (measured as total oil and gas production in thousands of bbls or as total oil and gas wells completed)

$e_t$  = error term representing unsystematic causes of wetland loss

$$0 < c < 1$$

According to this model, the effect of oil and gas activity on wetland loss extends indefinitely into the past, but the coefficients decline in a fixed proportion so that the effect of distance values of oil activity become negligible. The instantaneous loss from one unit of oil and gas activity  $O_t$  is b, while the cumulative loss from one unit of oil and gas activity  $O_t$  is  $b/(1-c)$ . The condition that c be less than one keeps the model stable. This condition should be met in our model because it is unlikely that one year of oil and gas activity would start a chain of ever increasing wetland loss which a value of  $c > 1$  would imply.

Equation (7) above may give a better characterization of the relation between oil and gas activity and wetland loss. However, it is impossible to estimate an infinite lag model without restricting the parameters in some way. Hence, we applied the Koyck transformation<sup>166</sup> to equation (7) to derive a model with a feasible number of parameters to estimate. If we lag equation (7) by one period and multiply both sides by c, we arrive at equation (8) below:

$$(8) \quad cWL^{T-1} = (c)(a) + (b)(c) [O_{t-1} + cO_{t-2} + c^2O_{t-3} + \dots] + (c)e_{t-1}$$

where:

$WL^{T-1}$  = total wetland loss in year  $t-1$ .

Subtracting equation (8) from equation (7) and rearranging terms yields equation (9) below:

$$(9) \quad WL^T = a_1 + bO_t + cWL^{T-1} + u_t$$

where:

$$u_t = e_t - (c)e_{t-1}$$

$$a_1 = (1-c)(a)$$

Equation (9) allows us to avoid the problems of infinite parameter estimation with a finite number of observations and multicollinearity associated with estimating many lagged coefficients of the same variable.

The Koyck transformation allows the estimation of an infinite lag model with only three parameters. However, we now have a stochastic explanatory variable in  $WL^{T-1}$ . Ordinary least squares estimation will still yield consistent estimates if there is no contemporaneous correlation between  $WL^{T-1}$  and the error term  $u_t$ . If the latter condition is not met, then OLS estimators are inconsistent and an alternative method of estimating equation (9) must be found.<sup>167</sup> Autocorrelation combined with a lagged dependent variable model will imply contemporaneous correlation between  $WL^{T-1}$  and  $u_t$ . The lagged dependent variable model without autocorrelation implies that  $WL^{T-1}$  is correlated with  $u_{t-1}$  because  $WL^{T-1}$  was in part determined by  $u_{t-1}$ . First order autocorrelation implies that  $u_t$  is correlated with  $u_{t-1}$ . Hence  $u_t$  is contemporaneously correlated with  $WL^{T-1}$  under first order autocorrelation. Thus, the appropriateness of OLS estimation of equation (9) depends on the evidence of autocorrelation. Since the Durbin-Watson test is biased toward 2 in the presence of lagged dependent variables, we used the Durbin-H test to check for first order autocorrelation.<sup>168</sup> The Durbin-h values were greater than 1.645, the 5% significance level, for all models. Hence our

data has the expected positive first order autocorrelation and OLS estimation of equation (9) will yield inconsistent estimates.

Due to autocorrelation in the lagged dependent variable model, we chose the Wallis two step instrumental variable technique to estimate equation (9).<sup>169</sup> The procedure is as follows: First, estimate equation (9) with OLS using  $O_t-1$  as the instrumental variable for  $WL^{T-1}$ . This step yields residuals and also predicted values for  $W$  which are used in subsequent steps. Second, use the residuals from this regression to generate an estimate of  $\rho$ , the autocorrelation parameter. Third, substitute the predicted values of  $WL^{T-1}$  from the first step for the actual  $WL^{T-1}$  in equation (9). Fourth, apply feasible generalized least squares to this equation. This process yields consistent estimates of  $a$ ,  $b$ , and  $c$  in equation (9) above. The results of our instrumental variables for all six equations are placed in Tables 7-4 and 7-5 below.

Table 7-4: Results of Regressions of Oil prod. and Wetland Loss (t-stat in parentheses)

Variable	Linear Interpol.	Linear Reg.	Exponential
Intercept	14,532.9 (3.45) **	14,163.0 (3.56) **	14,377.8 (3.28) **
WL T-1	0.256 (1.69) *	0.257 (1.80) *	0.263 (1.77) *
Qt	0.004 (1.91) *	0.005 (2.11) **	0.004 (1.63)
F stat	3.05 *	3.72 *	2.45
R2	.26	.30	.22

\*\*significant at 5%

\*significant at 10%

Table 7-5: Results of Regressions of Oil Wells and Wetland Loss (t-stat in parentheses)

Variable	Linear Interpol.	Linear Reg.	Exponential
Intercept	7608.8 (3.68) **	8959.7 (4.09) **	6149.4 (3.13) **
WL T-1	0.549 (5.27) **	0.501 (4.94) **	0.572 (4.82) **
Qt	0.730 (3.04) **	0.691 (2.98) **	0.842 (2.88) **
F stat	39.50 **	30.74 **	45.52 **
R2	.82	.78	.84

\*\*significant at 5%

\*significant at 10%

The parameter of  $WL T^{-1}$  is less than 1 for all regressions; thus the decay process is stable. The choice of wetland loss functional form did not make a significant difference in the results. The big difference is in whether wells or production data are used as independent variables. The equations using the production variable (Table 7-4) do not explain as high a percentage of wetland loss as the well data. In fact, the F-value for the exponential regression equation in Table 7-4, 2.45, is not significant at 5%. Hence the hypothesis that oil and gas production data do not explain wetland loss at all cannot be rejected for that equation. The statistical results are stronger for Table 7-5 where wells are the independent variable. All of the coefficients are positive and significant at 5%, and the t values for  $Qt$  indicate that oil and gas activity definitely has a significant



influence on wetland loss. However, as we indicated earlier, part of the reason for high  $R^2$ 's is the fact that important omitted variables that may be positively correlated with oil and gas activity have been omitted from this equation. Due to the increasing number of OCS wells and the fact that our equation does not discriminate between OCS and Coastal Zone wells, our statistics may indicate a stronger effect of oil and gas wells on wetland loss than is actually the case. The wells actually in the Coastal Zone have fallen steadily, while the number of OCS wells have dramatically increased (See Table 7A-4 in the Appendix). We would expect the average environmental impact to be smaller for an OCS well because they are actually drilled outside of the Coastal Zone. Their impacts arise due to the construction of new canals and use of old ones for shipping of oil and gas from OCS areas through the Coastal Zone. Although there are significant problems involved in the estimation process, the results in Tables 7-4 and 7-5 are the best that we can do with current data.

## 5. CCA for Louisiana Wetlands

In this section, we will use the physical wetland loss functions derived in the last two sections along with estimates of wetland values to form wetland capital consumption allowances for 1986, the latest year for which wetland loss and oil and gas activity data are available. In principle, a capital consumption allowance for wetland loss is equal to the stream of undiscounted wetland loss in each year multiplied by the present value of acres lost in each year as shown in equation (10) below.

$$(10) \quad CCA = WL_0 * PV + \frac{WL_1 * PV}{1+i} + \frac{WL_2 * PV}{(1+i)^2} + \dots$$

where:

$WL_t$  = undiscounted wetland loss in year  $t$  due to oil and gas. The wetland loss in each year is counted until there is less than one acre of wetland loss in a given year according to the Koyck lag model.

$PV$  = monetary present value of one acre lost in 1986.

$r$  = discount rate (3% or 8%)

Factoring the present value term from the right side of equation (10) yields equation (11) which expresses the CCA as the physical acre present value of wetlands multiplied by the monetary present value of one acre lost in 1986.

$$(11) \quad CCA = PV * \sum_{t=0}^n \frac{WL_t}{(1+r)^t}$$

where:

$WL_t$  = undiscounted wetland loss in year  $t$

$n$  = number of years of wetland loss until there is less than one acre of wetland loss in a given year according to the Koyck lag model.

Equation (11) will have a different form for the average and marginal approaches depending on how the acre present value term is calculated. The average approach to estimating wetland loss only yields the total loss per barrel or per well. Since there is no time dating of losses in the average approach, the CCA in year  $t$  is simply equal to the estimated oil and gas induced wetland loss in year  $t$  multiplied times the present value of an acre of wetland in year  $t$ . Thus equation (11) above simplifies to equation (12) below for the average approach.

$$(12) \quad CCA_t = PV * WL^{O\&G}$$

where:

$PV$  = present value of an acre lost in year  $t$ .

$WL_{O\&G}$  = estimate of oil and gas induced wetland loss in year  $t$  according to the average approach.

Using the marginal approach, there are two possible estimates of a CCA. The first estimate uses the long run marginal wetland loss multipliers  $[b/(1-c)]$  from the Koyck model. These multipliers yield the long run wetland loss due to an additional well or 1000 barrels. Since there is no time dating of these eventual long run losses, the "acre present value" in equation (11) is just the long run multiplier multiplied by the measure of oil and gas activity in year  $t$  (barrels or wells). The CCA in year  $t$  is this long run wetland loss multiplied by the present value of an acre lost in year  $t$ . Thus, for the marginal approach using the long run wetland loss multipliers without time dating, equation (11) above simplifies to equation (13) below.

$$(13) \quad CCA_t = PV * \frac{b}{(1-c)} * \text{oil and gas activity in year } t$$

where:

PV = present value of an acre lost in year  $t$ .

$b/(1-c)$  = long run marginal wetland loss multiplier

The second possible estimate of a CCA using the marginal approach uses the time dating of wetland loss from the Koyck model of equation (7). Since the timing of wetland loss is known, we can directly use equation (11) above to determine a physical acre present value. The CCA in year  $t$  is then equal to the present value of one acre times the acre present value of the stream of wetland losses.

We will calculate present values using 3% and 8% discount rates. The monetary present values used in the CCA calculations of the average and marginal approaches are the same. Stephen Farber and Robert Costanza have estimated the value of wetlands in a south Louisiana parish (Terrebonne) using a willingness to pay (WTP) approach and an energy analysis (EA) approach.<sup>170</sup> If we assume that the values of this

parish are representative of Louisiana wetland values as a whole, then we can use their per acre values in the construction of our capital consumption allowances. The willingness to pay methodology estimates the value of the following separate wetland services: commercial fishing and trapping, recreation, and storm wind damage protection.

The commercial fishing and trapping estimates were derived through simple production functions in which the marginal product of a unit of wetland could be isolated. In some cases (menhaden, muskrat, and nutria), it was necessary to assume that the marginal product and average product were the same due to data limitations. The per acre present values at 8% and 3% discount rates of wetlands for commercial fishing and trapping were \$468.25 and \$1248.67 respectively in 1983 dollars. The value of wetlands for recreation was estimated using both travel cost and contingent valuation methodologies. The latter estimates based on a recreational use survey were within the range of estimated travel cost estimates. The per acre present values at 8% and 3% of wetlands for recreation was \$111.00 and \$1500 respectively in 1983 dollars. The value of wetlands as protection from storm wind damage was estimated by deriving a wind damage decay function in which damages fall as distance from landfall increases.<sup>171</sup> Historical Louisiana storm probabilities for storms of different intensities were combined with Corps of Engineers wind damage estimates to yield an expected damage function. The value of a given area of wetlands for wind damage protection is then the difference between two expected damage functions with and without the given area. This methodology yielded per acre present values at 8% and 3% of wetlands for storm wind damage protection of \$7.48 and \$33.85 respectively in 1983 dollars. The total discounted value per acre of wetlands for all three services was \$586.73 at 8% and \$2782.52 at 3% in 1983 dollars.

The economic valuation of wetlands based on willingness to pay is incomplete because some important values such as flood protection, option, and existence values

have not been estimated. Thus it would be useful to have an upper bound value of an acre of wetlands lost. Estimates of wetland values based on energy analysis (described in chapter 5) provide a reasonable upper bound estimate. Energy analysis calculates the total energy captured by natural economic systems and then converts it to dollars using a constant energy/dollar conversion factor derived from a comparison of energy and conventional input-output tables. An energy valuation can be considered an upper bound value of the products of natural ecosystems because it includes all energy captured by natural systems although all of it may not be valued by humans. Although energy analysis does not include values such as option value which are not tied closely to physical productivity of systems, it is the best available estimate of an upper bound economic value for wetlands. This methodology yields a range of present values at 8% of \$6400 to \$10,602 per acre in 1983 dollars.<sup>172</sup> The range at 3% is \$17,067 to \$28,267. This estimate is likely to be an upper bound value of the willingness to pay for wetlands since, at the 3% discount rate, the upper range is 10 times higher than the wetland values calculated with the willingness to pay methodology.

Now we have two ranges of monetary values per acre to use in constructing monetary capital consumption allowances. Using the 1983 and 1986 fixed weighted price indices for GNP, we can convert the \$586.73 and \$2782.52 values based on WTP to \$648.73 and \$3076.54 in 1986 dollars.<sup>173</sup> Similarly, the \$10,602 and \$28,267 values based on EA are equal to \$11,722 and \$31,254 in 1986 dollars. These per acre wetland values will be used in equations (11), (12), and (13) in deriving estimated capital consumption allowances using the average and marginal approaches.

We will first calculate a CCA using the average approach in Table 7-6 below.

Table 7-6: Estimated 1986 CCA Using the Average Measure of Wetland Loss

	<u>Production</u>	<u>Wells</u>
Estimated WLO&G	6,973 acres	13,245 acres
WTP - PV (\$)		
3%	\$3076.54	\$3076.54
8%	\$648.73	\$648.73
CCA - WTP (\$million)		
3%	\$21.453	\$40.749
8%	\$4.524	\$8.592
EA - PV (\$)		
3%	\$31,254	\$31,254
8%	\$11,722	\$11,722
CCA - EA (\$million)		
3%	\$217.934	\$413.959
8%	\$81.738	\$155.258

The CCA estimates in Table 7-6 are derived by multiplying the estimated 1986 wetland loss due to oil and gas activity (using either the production or the well measures) by the 1986 present value of one acre lost in that year. The average loss estimates assume loss due to 1986 activity will ultimately equal that implied by the long run historical averages shown in Table 7-1. Given oil and production in 1986 of 1,106,803 thousand barrels, and average losses of .0063 acres/thousand barrels [from equation (1)], estimated eventual loss due to 1986 production activity is 6,973 acres, as shown in row 1 of Table 7-6. Using the 6,973 production estimate of eventual wetland loss, the CCA - WTP at 8% is then \$648.73 per acre multiplied by 6,973 acres, or \$4.524 million in Table 7-6. The capital consumption allowances using wells as an oil and gas activity measure and energy analysis present value estimates are calculated in the same manner.

Now we turn to calculation of a CCA using the marginal approach. Our first method of estimating marginal capital consumption allowances is through the use of the long run wetland loss multipliers  $[b/(1-c)]$ . According to equation (13), the CCA is equal to the long run wetland loss multiplied times the present value of acres lost. The estimated long run wetland loss is equal to  $b/(1-c)$  multiplied by the measure of oil and gas activity in 1986. This long run wetland loss is presented in Table 7-7 below.

Table 7-7: Estimated 1986 Wetland Loss Using Long Run Marginal Estimator,  $b/(1-c)$

	<u>Production</u>	<u>Wells</u>
Estimated $[b/(1-c)]$		
Linear interpolation	.0054	1.6186
Linear regression	.0067	1.3848
Exponential	.0054	1.9673
Estimated Wetland Loss		
Linear Interpolation	5,977 acres	17,706 acres
Linear regression	7,416 acres	15,148 acres
Exponential	5,977 acres	21,520 acres

The long run wetland loss multipliers in Table 7-7 tell how many acres of wetlands will be eventually destroyed by one additional well or 1000 more barrels. For example, the marginal long run effect of one thousand more barrels is .0067 acres of wetland loss using the linear regression equation. Given the 1986 oil and gas production of 1,106,803 thousand barrels, the estimated wetland loss using the linear regression equation is .0067 acres per thousand barrels multiplied by 1,106,803 thousand barrels, or 7,416 acres in Table 7-7 above. All of the long run losses in Table 7-7 are calculated in the same manner. The loss estimates using production data are much smaller than

those using well data. This may be attributable to the possibility that wetland loss is more immediately and directly affected by drilling activity than by production activity.

The estimated marginal wetland losses using the production data in Table 7-7 are similar in magnitude to the 1986 average loss of 6,973 acres in Table 7-6. The marginal losses using the well data in Table 7-7 are larger than the 1986 average loss of 13,245 acres in Table 7-6. However, we are using the low Turner-Cahoon estimate (30%) of oil and gas induced wetland loss to calculate our average losses in Table 7-6. The marginal losses using the well data in Table 7-7 are well below the high Turner-Cahoon estimate (59%) of 1986 oil and gas induced wetland loss of 26,048 acres.<sup>174</sup> The similarity of the average and marginal loss estimates is not surprising since the average estimates embody all long run responses, and the 32 year time period is fairly long.

The estimated wetland losses in Table 7-7 must be multiplied times the present values of an acre lost to form the capital consumption allowances for 1986. These CCAs are presented in Tables 7-8 and 7-9 below. Table 7-8 presents the CCA using a 3% discount rate, while Table 7-9 uses an 8% discount rate. In each table, the CCA - WTP is equal to the acres lost (from Table 7-7) multiplied times the WTP - PV of an acre lost. For example, in Table 7-8, the production CCA using linear interpolation is 5,977 acres lost multiplied by \$3,076.54 per acre which is equal to \$18.388 million dollars. In each table, the CCA - EA are calculated in the same manner.



Table 7-8: Estimated 1986 CCA using Long Run Marginal Estimator,  $b/(1-c)$ ,  $r=3\%$ 

	Acres Lost	WTP - PV (\$)	CCA - WTP (\$million)	EA - PV (\$)	CCA - EA (\$million)
<u>Production</u>					
Linear inter.	5,977	\$3,076.54	\$18.388	\$31,254	\$186.805
Linear reg.	7,416	\$3,076.54	\$22.816	\$31,254	\$231.780
Exponential	5,977	\$3,076.54	\$18.388	\$31,254	\$186.805
<u>Wells</u>					
Linear inter.	17,706	\$3,076.54	\$54.473	\$31,254	\$553.383
Linear reg.	15,148	\$3,076.54	\$46.603	\$31,254	\$473.436
Exponential	21,520	\$3,076.54	\$66.207	\$31,254	\$672.586

Table 7-9: Estimated 1986 CCA using Long Run Marginal Estimator,  $b/(1-c)$ ,  $r=8\%$ 

	Acres Lost	WTP - PV (\$)	CCA - WTP (\$million)	EA - PV (\$)	CCA - EA (\$million)
<u>Production</u>					
Linear inter.	5,977	\$648.73	\$3.877	\$11,722	\$70.062
Linear reg.	7,416	\$648.73	\$4.811	\$11,722	\$86.930
Exponential	5,977	\$648.73	\$3.877	\$11,722	\$70.062
<u>Wells</u>					
Linear inter.	17,706	\$648.73	\$11.486	\$11,722	\$207.550
Linear reg.	15,148	\$648.73	\$9.827	\$11,722	\$177.565
Exponential	21,520	\$648.73	\$13.961	\$11,722	\$252.257

The second method of determining a CCA within the marginal approach uses the time dated series of losses from the Koyck model in equation (7). The time dating allows calculation of the physical present value of physical acres lost according to equation

(11). In order to determine this acre present value using the Koyck lag model, we extended the lags out from 1986 [using equation (7)] until there was less than one acre of wetland loss in a given year. This stream of wetland loss was then discounted at 3% and 8%. At the 8% discount rate, the landloss decay process took 7 years for all 3 equations using oil and gas production data. For the equations using well data at the 8% rate, this process took 15 years for the interpolation model, 13 years for the linear regression, and 17 years for the exponential equation. At the 3% discount rate using the production data, the landloss decay process took 7 years for the interpolation model, 8 for the linear regression, and 7 for the exponential equation. For the equations using well data at 3%, this process took 16 years for the interpolation model, 14 for the linear regression, and 17 for the exponential equation. The resulting acre present values are shown in Table 7-10 below. Of course, these loss estimates are all lower than the undiscounted wetland losses using the multiplier  $[b/(1-c)]$  in Table 7-7.

Table 7-10: Estimated Acre Present Values Using Marginal Estimates

	<u>r = 3%</u>	<u>r = 8%</u>
<u>Production</u>		
Linear interpolation	5,911 acres	5,818 acres
Linear regression	7,030 acres	6,934 acres
Exponential	5,911 acres	5,818 acres
<u>Wells</u>		
Linear interpolation	17,086 acres	16,219 acres
Linear regression	14,728 acres	14,099 acres
Exponential	20,693 acres	19,556 acres

According to equation (11), the 1986 CCA is equal to the discounted acre present values above multiplied times the monetary present value of an acre of wetland in 1986. The capital consumption allowances using the different oil and gas activity measures and the WTP and EA valuation measures are presented in Tables 7-11 and 7-12 below. Table 7-11 presents the CCA for a 3% discount rate, and Table 7-12 presents the CCA for an 8% rate. In each table, the CCA - WTP is equal to the acres lost (from Table 7-10) multiplied times the WTP - PV of an acre lost. For example, in Table 7-11, the production CCA using linear interpolation is 5,911 acres lost multiplied by \$3,076.54 per acre which is equal to \$18.185 million dollars. In each table, the CCA - EA are calculated in the same manner.

Table 7-11: Estimated CCA Using Acre Present Value Marginal Estimates,  $r = 3\%$

	Acres Lost	WTP - PV (\$)	CCA - WTP (\$million)	EA - PV (\$)	CCA - EA (\$million)
<u>Production</u>					
Linear inter.	5,911	\$3,076.54	\$18.185	\$31,254	\$184.742
Linear reg.	7,030	\$3,076.54	\$21.628	\$31,254	\$219.716
Exponential	5,911	\$3,076.54	\$18.185	\$31,254	\$184.742
<u>Wells</u>					
Linear inter.	17,086	\$3,076.54	\$52.566	\$31,254	\$534.006
Linear reg.	14,728	\$3,076.54	\$45.311	\$31,254	\$460.309
Exponential	20,693	\$3,076.54	\$63.663	\$31,254	\$646.739

Table 7-12: Estimated CCA Using Acre Present Value Marginal Estimates,  $r = 8\%$ 

	Acres Lost	WTP - PV (\$)	CCA - WTP (\$million)	EA - PV (\$)	CCA - EA (\$million)
<u>Production</u>					
Linear inter.	5,818	\$648.73	\$3.774	\$11,722	\$68.199
Linear reg.	6,934	\$648.73	\$4.498	\$11,722	\$81.280
Exponential	5,818	\$648.73	\$3.774	\$11,722	\$68.199
<u>Wells</u>					
Linear inter.	16,219	\$648.73	\$10.522	\$11,722	\$190.119
Linear reg.	14,099	\$648.73	\$9.146	\$11,722	\$165.268
Exponential	19,556	\$648.73	\$12.687	\$11,722	\$229.235

We have now calculated three sets of capital consumption allowances: one set using the average approach in Table 7-8, one set using the marginal approach with undiscounted wetland losses based on the multiplier  $[b/(1-c)]$  in Tables 7-8 and 7-9, and one set using the marginal approach with discounted wetland losses in Tables 7-11 and 7-12. Each CCA is an estimate of the capitalized environmental loss to Louisiana and the United States of 1986 oil and gas activity in the Louisiana coastal zone. The 8% willingness to pay CCA estimates for the average and marginal approaches using the production data are very similar, regardless of the method of estimation, ranging from \$3.8 million to \$4.5 million. The 8% willingness to pay estimates for the average and marginal approaches using well data are not as similar in magnitude across methods of estimation; ranging from \$8.6 million to \$12.7 million. All of the production estimates are low relative to well estimates. This is expected if wetland loss is directly related to well activity and the marginal effect of more production from an existing well is very small. The average estimates are greater than the statistical model production estimates, but less than the statistical model well estimates.

Due to larger per acre values, the energy analysis CCA estimates are significantly higher than the willingness to pay estimates using either production or wells. The largest energy analysis CCA estimate of \$646.739 million is over 10 times higher than the largest willingness to pay CCA estimate of \$63.663 million (exponential well model in Table 7-11). Hence the capital consumption allowances based on energy analysis should provide a reasonable upper bound for the allowances based on willingness to pay which do not include all wetland values. Given the 1986 U.S. net national product (NNP) of 3,788.4 billion 1986 dollars, the largest estimate of 1986 wetland loss to be subtracted from NNP would be only .017% of NNP.

## 6. Summary

In this chapter, we have provided an illustrative empirical example of environmental accounting by estimating various capital consumption allowances for the loss of Louisiana wetlands due to oil/gas production. The theoretically correct measure of the capital consumption allowance is the minimum of the cost of replacing the lost services or the social value of the benefits lost. In the absence of comprehensive data on costs, we used estimates of current social values of wetlands multiplied by the physical acres lost as our capital consumption allowance.

Two different methods were used in this study to estimate the physical acres lost due to oil/gas production. The first relied on the range of total oil/gas related losses estimated in the Turner-Cahoon study. It yielded two average wetland loss functions for the entire 1955-86 time period. This method does not explicitly allow estimation of the lagged effects of oil and gas activity on wetland loss, and it relies on arguable consensus estimates of the range of oil/gas related losses. Thus we also estimated physical loss functions by a statistical method which did not assume any apriori range of wetland losses due to oil/gas production. Three different pseudo wetland loss functions were

combined with annual oil and gas production data and oil and gas well data to estimate physical losses due to oil/gas production. This method's primary defect is the omitted variable problem. The final monetary capital consumption allowances based on physical damage functions and estimates of wetland values are probably not very accurate due to inadequate data for other important causal mechanisms of wetland loss, incomplete accounting for all wetland values using the willingness to pay method, and uncertainty as to the validity of the energy analysis value estimates. However, our estimates of capital consumption allowances indicate the type of procedure necessary to estimate the macro-level tradeoff between oil/gas production and wetland loss.

The problems we have encountered in developing a capital consumption allowance for wetland loss due to oil and gas activity indicate the type of data needed for better estimates of a wetlands CCA. First and most important, we need more data on the primary determinants of the recent landloss. Specifically, we need a proxy variable for the diversion of sediments from the wetlands to the Mississippi as a result of the levees built over the last half century. Another important variable may be a measure of the destruction of wetlands over time due to house, road, and industrial building construction. Second, in the absence of general agreement on the usefulness of energy analysis valuation, we need a more thorough accounting of all wetland values using the willingness to pay methodology.

## Appendix to Chapter 7: Econometric Procedures and Data Tables

### Part I: Description of Econometric Procedures for Finite Lag model

Our simple model is described by equation (1) below [Equation (4) in text.]

$$(1) \text{ WLT} = [\text{Intercept, } Q_t, Q_{t-1}, Q_{t-2}, \dots] + e_t$$

where:

WLT = total wetland loss in year t

$Q_t$  = total oil and gas activity in year t (measured as total oil and gas production in thousands of barrels or as total oil, gas, and dry wells completed).

$e_t$  = error term representing unsystematic causes of wetland loss.

Since the procedures and problems with the results are similar for all our six equations, we will illustrate our procedures using the just the linear interpolation model with production data.

Step 1: Choose maximum lag length we are willing to consider given the fact that we have only 32 observations. We choose a maximum lag length of 9 lags ( $Q_{t-1}$  through  $Q_{t-9}$ . The current observation  $Q_t$  does not count as a lag).

Step 2: Check for autocorrelation because we must have a "true model" before we determine the appropriate lag length. We use the conventional Durbin-Watson statistic to check for autocorrelation. The DW value of .71 indicates positive first order autocorrelation. Correct the autocorrelation using conventional feasible generalized least squares procedures. The estimate of  $\rho = .62$ , the autocorrelation parameter used in the transformation matrix, is found through the use of Theil's estimator (p. 212, Fomby, et al.).

Step 3: Once the above model has been corrected for autocorrelation, use a pretesting procedure to determine the appropriate lag length. Starting with a nine lag model, we drop the longest lagged value if the t-statistic is not significant at 5%. We continue dropping lags until the coefficient of the longest lagged value is significant at 5%. The coefficients of the 9th, 8th, 7th, 6th, and 5th lag lengths were not significant in this series of regressions and pretests. The t-statistic of the coefficient 4th lag (2.52) was positive and significant at 5%. Hence we choose a lag length of four. [The model has an intercept,  $Q_t$ ,  $Q_{t-1}$ ,  $Q_{t-2}$ ,  $Q_{t-3}$ , and  $Q_{t-4}$ ]

Step 4: Fit an Almon polynomial distributed lag (PDL) to the 4 lag model. This technique approximates the lag structure as a fairly low degree polynomial in order to reduce multicollinearity and to increase the degrees of freedom of the model. For example, if the coefficients of the four lag model have an inverted U-shaped pattern of an initial increase and then a gradual decrease, then we may be able to approximate this pattern by a second degree polynomial. This will place two restrictions on the model and hence

increase the efficiency of the estimates as long as the polynomial degree is a good approximation of the actual pattern of the lagged coefficients.

We choose the degree of the Almon PDL through a series of F tests with restricted and unrestricted models. First, estimate the model with polynomial degree that is equal to the number of lag coefficients. In this case, use a 4th degree polynomial to estimate the 4 lag model. This is equivalent to putting no restrictions on the coefficients because the PDL estimation involves 5 parameters ( $a + bx + cx^2 + dx^3 + ex^4$ ) as does the model without a polynomial structure (coefficients of  $Q_t, Q_{t-1}, Q_{t-2}, Q_{t-3}, Q_{t-4}$ ). Note that the intercept is not part of the PDL process; the PDL just imposes a structure on the lag coefficients, not on the intercept. The estimation of a 4th degree polynomial is our unrestricted model. Second, estimate the model with a polynomial degree that is one less than the degree of the unrestricted model. In this case, estimate the model with a third degree polynomial. This is our restricted model. Third, calculate a conventional F-test which compares the sum of squared errors of the restricted and unrestricted models. If the F value is not significant at 5%, then accept the hypothesis that the highest polynomial degree is zero. Fourth, repeat this process until the F test rejects the hypothesis that the highest polynomial degree is zero. This will reveal the degree of polynomial to use in estimating the lagged model. In this case, the F-tests indicated that the 4 lag model could be fitted as a first degree polynomial (a straight line of the form  $a + bx$ ), thus saving 3 degrees of freedom over a model which did not use the Almon PDL structure.

Step 5: Check the results to determine if they are plausible. They are shown in equation (2) below; the t values are placed in parentheses below the coefficients.

$$(2) \text{ WLT} = 19711.9 - .0040 Q_t - .0013 Q_{t-1} + .0013 Q_{t-2} + .0039 Q_{t-3} + .0066 Q_{t-4} + e_t$$

$$(7.11) \quad (-1.89) \quad (-1.17) \quad (3.14) \quad (4.07) \quad (3.44)$$

In this case, the results are not plausible because the coefficient of the last lagged value is significantly higher than the other coefficients. The Almon PDL model assumes a finite lag length; hence the expectation is that the effect of each coefficient of the independent variable  $Q$  on the dependent variable  $W$  will decline as we get nearer to the last finite lag length (because all coefficients of lag lengths beyond the last one are considered to be zero). However, the coefficient of  $Q_{t-4}$ , .0066, is the largest coefficient. The model says that the effect of oil and gas activity on wetland loss increases from the second through the 4th year and then suddenly drops to zero in the 5th year. This does not appear to be a plausible description of the way such a process would work in nature. Also, the coefficient of  $Q_t$  is negative and almost significant at 5%. This indicates that current oil production causes wetland building (negative wetland loss) in that year, a conclusion which makes no sense in the light of all evidence on the relation between oil and gas activity and wetland loss.

Step 6: Due to the above considerations, we decide to drop the lag model and try to fit equation (1) above with an infinite lag model. The procedures for developing the infinite lag model are described in detail in the text.



Part II: Data TablesTable 7A-1: OCS Oil and Gas Production 1955-1986

<u>Year</u>	<u>OCS Oil (bbls)</u>	<u>OCS Gas (MCF)</u>	<u>Total in bbl.</u>
1955	6703528	81279042	21008639
1956	11001248	82892538	25590335
1957	16064395	82568807	30596505
1958	24769037	127692848	47242978
1959	35697264	207156296	72156772
1960	49665891	273034451	97719954
1961	64330078	318280095	120347375
1962	89733099	451952659	169276767
1963	104526436	564352606	203852495
1964	122495173	621731438	231919906
1965	144964868	645589469	258588615
1966	187831472	965387849	357739733
1967	218995828	1087262804	410354082
1968	263825359	1413467606	512595658
1969	300159292	1822544142	620927061
1970	333411492	2273147040	733485371
1971	385760351	2634014031	849346820
1972	387590662	2881364733	894710855
1973	374196856	3055628236	911987426
1974	342435496	3349170864	931889568
1975	313592559	3332169057	900054313
1976	301887002	3499865900	917863400
1977	290771605	3647513674	932734012
1978	278071535	4149731136	1008424215
1979	271008916	4158521710	1002908737
1980	256688082	4013707434	963100590
1981	255875717	4106494590	978618765
1982	275513489	3803740050	944971738
1983	298093559	3173892354	856698613
1984	318024622	3578740570	947882962
1985	338901863	3116884490	887473533
1986	340152276	2927832264	855450754
55-79	4919489442	41726319031	12263321591
55-86	7002739050	66447610783	18697518548

Source: Federal Offshore Statistics: 1986. Leasing, Exploration, Production, & Revenues. Compiled by Walter M. Harris. U.S. Department of the Interior, Minerals Management Service, Offshore Information & Publications, pp. 53-54.

The conversion factor to change thousand cubic feet (MCF) of natural gas to barrels of oil equivalent is 0.176. This was derived from conversion factors in Appendix D, p. 104, of the 1981 International Energy Annual, September 1982. Energy Information Administration, Office of Energy Markets and End Use, U.S. Department of Energy, Washington, D.C., 20585.

Table 7A-2: Louisiana Coastal Zone Oil and Gas Production, 1955-1986

<u>Year</u>	<u>Oil Prod(bbl)</u>	<u>Nat. Gas (MCF)</u>	<u>Total in bbls</u>
1955	150000000	497000000	237472000
1956	175000000	619000000	283944000
1957	195000000	743000000	325768000
1958	181000000	830000000	327080000
1959	214000000	988000000	387888000
1960	244000000	1182000000	452032000
1961	260000000	1259000000	481584000
1962	320000000	1530000000	589280000
1963	322000000	1675000000	616800000
1964	333000000	1806000000	650856000
1965	364000000	2073000000	728848000
1966	409000000	2472000000	844072000
1967	483000000	2913000000	995688000
1968	501000000	3250000000	1073000000
1969	479000000	3619000000	1115944000
1970	513000000	3788000000	1179688000
1971	492000000	3721000000	1146896000
1972	406000000	3726000000	1061776000
1973	345000000	3365000000	937240000
1974	291000000	2985000000	816360000
1975	239000000	2522000000	682872000
1976	203000000	2195000000	589320000
1977	185000000	2102000000	554952000
1978	167000000	1977000000	514952000
1979	146000000	1859000000	473184000
1980	133000000	1606000000	415656000
1981	119000000	1441000000	372616000
1982	104000000	1228000000	320128000
1983	97000000	1036000000	279336000
1984	100000000	1060000000	286560000
1985	98000000	1090000000	289840000
1986	97000000	877000000	251352000
55-79	7617000000	53696000000	17067496000
55-86	8365000000	62034000000	19282984000

Source: Lindstedt, D.M., L.L. Nunn, J. C. Holmes, Jr., History of Oil and Gas Development in Coastal Louisiana. Louisiana Geological Survey Resource Information Series #7. Louisiana Geological Survey, Baton Rouge, LA. In press. 100+ pages.

Table 7A-3: OCS and Louisiana Coastal Zone Oil and Gas Production, 1955-1986

<u>Year</u>	<u>OCS (bbbls)</u>	<u>Coastal Zone (bbbls)</u>	<u>OCS + Coast (bbbls)</u>
1955	21008639	237472000	258480639
1956	25590335	283944000	309534335
1957	30596505	325768000	356364505
1958	47242978	327080000	374322978
1959	72156772	387888000	460044772
1960	97719954	452032000	549751954
1961	120347375	481584000	601931375
1962	169276767	589280000	758556767
1963	203852495	616800000	820652495
1964	231919906	650856000	882775906
1965	258588615	728848000	987436615
1966	357739733	844072000	1201811733
1967	410354082	995688000	1406042082
1968	512595658	1073000000	1585595658
1969	620927061	1115944000	1736871061
1970	733485371	1179688000	1913173371
1971	849346820	1146896000	1996242820
1972	894710855	1061776000	1956486855
1973	911987426	937240000	1849227426
1974	931889568	816360000	1748249568
1975	900054313	682872000	1582926313
1976	917863400	589320000	1507183400
1977	932734012	554952000	1487686012
1978	1008424215	514952000	1523376215
1979	1002908737	473184000	1476092737
1980	963100590	415656000	1378756590
1981	978618765	372616000	1351234765
1982	944971738	320128000	1265099738
1983	856698613	279336000	1136034613
1984	947882962	286560000	1234442962
1985	887473533	289840000	1177313533
1986	855450754	251352000	1106802754
55-79	12263321592	17067496000	29330817592
55-86	18697518547	19282984000	37980502547

Source: This table is derived from Tables A and B above.

Table 7A-4: OCS and La. Coastal Zone Wells Completed (oil, gas, dry) 1955-1986

<u>Year</u>	<u>OCS</u>	<u>Coastal Zone</u>	<u>OCS + Coastal Zone</u>
1955	235	1124	1359
1956	353	1022	1375
1957	585	1092	1677
1958	791	1111	1902
1959	1455	1501	2956
1960	1916	1597	3513
1961	2456	1619	4075
1962	3079	1650	4729
1963	3617	1549	5166
1964	4281	1500	5781
1965	4694	1107	5801
1966	3254	964	4218
1967	3681	814	4495
1968	4147	939	5086
1969	4567	617	5184
1970	5099	671	5770
1971	5429	567	5996
1972	5727	469	6196
1973	6104	493	6597
1974	5912	443	6355
1975	5776	413	6189
1976	6102	402	6504
1977	7422	405	7827
1978	7758	399	8157
1979	8169	500	8669
1980	8618	525	9143
1981	9094	599	9693
1982	9707	560	10267
1983	10333	437	10770
1984	10156	541	10697
1985	10498	486	10984
1986	10624	315	10939
55-86	171639	26,431	198070

Source: OCS well data is from Federal Offshore Statistics, 1986, pp. 25-31. The 1984-86 OCS totals were only available for the four state unit of Louisiana, Mississippi, Alabama, and Florida. Thus we estimated Louisiana totals for those years by using the percentage of Louisiana wells (98.8%) in the Louisiana plus Mississippi plus Alabama plus Florida totals from 1980-1983.

Coastal Zone well data from 1955-1978 is derived from unpublished data at the Louisiana Geological Survey, Baton Rouge, LA. The 1979-1986 Louisiana well data is only available for the entire South Louisiana Zone. Hence we derived Coastal Zone data using a simple extrapolation procedure. The percentage of South Zone wells in the Coastal Zone from 1974-78 (.36) was multiplied times the South Zone totals for 1979-86 to derive the Coastal Zone well totals for the latter period. The percentage of South Zone wells in the Coastal Zone from 1955-78 (.41) was not used because the percentage of

Coastal Zone wells in the South Zone has fallen steadily in that time period. The data for the South Louisiana Zone was from Louisiana Energy Statistics 1960-1985, by the LSU Center for Energy Studies.

Table 7A-5: Pseudo Wetland Loss Functions: Annual Acres Lost

<u>Year</u>	<u>Interpolation</u>	<u>Linear Regression</u>	<u>Exponential</u>
1955	13,440	13,115	13,889
1956	14,187	13,904	14,406
1957	14,934	14,693	14,879
1958	15,681	15,482	15,397
1959	16,428	16,271	15,892
1960	17,175	17,060	16,455
1961	17,922	17,849	16,995
1962	18,669	18,638	17,468
1963	19,416	19,427	18,166
1964	20,163	20,216	18,728
1965	20,910	21,005	19,426
1966	21,657	21,794	20,056
1967	22,400	22,583	20,777
1968	23,138	23,372	21,497
1969	23,876	24,161	21,992
1970	24,614	24,950	22,938
1971	25,352	25,739	23,681
1972	26,090	26,528	24,671
1973	26,828	27,317	25,841
1974	27,566	28,106	26,449
1975	28,304	28,895	27,057
1976	29,042	29,684	27,687
1977	29,780	30,473	28,925
1978	30,518	31,262	29,668
1979	31,256	32,051	31,064
1980	32,000	32,840	31,807
1981	33,067	33,629	33,292
1982	34,134	34,418	34,080
1983	35,201	35,207	35,273
1984	36,268	35,996	36,511
1985	37,335	36,785	37,344
1986	38,400	37,574	39,122

145 Paul H. Templet and Klaus J. Meyer-Arendt, "Louisiana Wetland Loss: A Regional Water Management Approach to the Problem," Environmental Management, Vol. 12, No. 2, p. 181.

146 Daniel K. Tabberer and Carroll L. Cordes, Pipeline Impacts on Wetlands Final Environmental Assessment, U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, p. 3.

147 R. E. Turner and D. R. Cahoon, editors, 1987. Causes of Wetland Loss in the Coastal Central Gulf of Mexico. Volume I: Executive Summary. Final report submitted to Minerals Management Service, New Orleans, Louisiana, p. 1.

148 "Louisiana Wetland Loss: A Regional Water Management Approach to the Problem," p. 181.

149 Causes of Wetland Loss in the Coastal Central Gulf of Mexico. Volume I: Executive Summary, p. 4.

150 N. J. Craig, R. E. Turner, and J. W. Day Jr., "Land Loss in Coastal Louisiana (U.S.A.)," Environmental Management, Vol. 3, No. 2, p. 138.

151 W. B. Johnson and J. G. Gosselink, "Wetland Loss Directly Associated with Canal Dredging in the Louisiana Coastal Zone," in Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options edited by Donald F. Boesch. (Washington, D.C.: U.S. Fish and Wildlife Service, Biological Services Program, 1982), pp. 60-72.

152 W. Scaife, R. E. Turner, and R. Costanza, "Coastal Louisiana recent land loss and canal impacts," Environmental Management, Vol. 7, 1983, pp. 433-442.

153 Causes of Wetland Loss in the Coastal Central Gulf of Mexico. Volume I: Executive Summary, p. 15.

154 R. E. Turner and C. Neill, "Revisiting Impounded Wetlands after 70 years," in Proceedings of the Water Quality and Wetlands Management Conference. Edited by R. J. Yarnell. New Orleans, Louisiana, 1984.

155 H. Jesse Waker, et al, "Wetland Loss in Louisiana," Geografiska Annaler, Vol. 69 A, (1987), pp. 189-200.

156 Causes of Wetland Loss in the Coastal Central Gulf of Mexico. Volume II: Technical Narrative, p. 201.

157 "Louisiana Wetland Loss: A Regional Water Management Approach to the Problem," p. 181.

158 Causes of Wetland Loss in the Coastal Central Gulf of Mexico. Volume I: Executive Summary. The loss range for OCS activity only was 8 to 17%, while the loss range for Coastal Zone activity only was 22 to 42%.

159 Oil and gas production and well data and sources are listed in Tables A, B, and C in the Appendix to this chapter. The procedure used to calculate total wetland loss from 1955 to 1986 is as follows: In Section 4 of this chapter, we calculate three annual wetland loss functions for this period based on 4 annual wetland loss data points. Integration of these functions from 1955 to 1986 yields three estimates of total wetland loss (805,751 acres for linear interpolation, 811,024 for linear regression, and 781,433 for exponential regression) over the period. We took a simple average of the three totals to derive the total wetland loss (799,403 acres) used in construction of Table 7-1.

<sup>160</sup>S. M. Gagliano, Hyuck J. Kwon, and Johannes L. van Beek, "Deterioration and Restoration of Coastal Wetlands," Hydrological and Geological Studies of Coastal Louisiana, Report No. 9, Coastal Studies Institute, Center for Wetland Resources, Louisiana State University. This study estimated a loss rate of 16.7 square miles per year over the period 1945-1970. Since 1955 is the midpoint, a reasonable estimate of erosion in Deltaic plain in 1955 is 16.7. However, this does not include losses in the Chenier plain. Hence we assumed that the relation between erosion in Deltaic and Chenier plains in 1955 was the same as other years when more precise extrapolations were made. See the following footnotes concerning this table.

<sup>161</sup>S. M. Gagliano, Klaus J. Meyer-Arendt, and Karen M. Wicker, "Land Loss in the Mississippi River Deltaic Plain," Transactions- Gulf Coast Association of Geological Societies, Vol. 31, 1981. Land loss for Deltaic plain in 1980 was estimated at 39.4 square miles. The addition of erosion in the Chenier plain increases the total coastal loss to approximately 50 square mile per year in 1980. Land loss for Deltaic plain in 1967 was estimated at 28.1 square miles. There is no data on erosion in Chenier plain for 1967; hence we assumed that the relation between erosion in the two plains was the same in 1967 and 1980. This yields the 35 square mile loss for all of coastal Louisiana in 1967.

<sup>162</sup>Louisiana Wetland Loss: A Regional Water Management Approach to the Problem," p. 181.

<sup>163</sup>Louisiana Wetland Loss: A Regional Water Management Approach to the Problem," p. 181.

<sup>164</sup>T. B. Fomby, R. Carter Hill, and Stanley R. Johnson. Advanced Econometric Methods (New York: Springer-Verlag, 1984), pp. 400-405.

<sup>165</sup>Causes of Wetland Loss in the Coastal Central Gulf of Mexico. Volume I: Executive Summary, p. 1.

<sup>166</sup>J. Johnston, Econometric Methods, 3rd edition. (New York: McGraw-Hill Book Company, 1984), pp. 346-349.

<sup>167</sup>Advanced Econometric Methods, pp. 238-241.

<sup>168</sup>*ibid*, p. 244.

<sup>169</sup>The Wallis two step instrumental variable estimator yields consistent but not asymptotically efficient estimates for the coefficients of a lagged dependent variable model with autocorrelation. Although maximum likelihood estimators are asymptotically efficient, this technique was not feasible in our problem due to the construction of our smooth wetland loss functions. The maximum likelihood method uses  $Wt-1$  as an explanatory variable rather than the predicted value of  $Wt-1$  used in the instrumental variable method. The maximum likelihood estimation of equation (9) in the text yields a  $Wt-1$  coefficient of .99 to 1.0 depending on the value of  $\rho$  in the iteration procedure. This is because  $yt-1$  is an excellent predictor of  $yt$  in a smoothly constructed function. The instrumental variable technique yields more realistic estimates of the parameters of equation (9) because the predicted value of  $Wt-1$  will not 'artificially' explain all the variation in  $Wt$ . The Wallis two-step and maximum likelihood estimators are discussed in Advanced Econometric Methods, pp. 242-251.

<sup>170</sup>Stephen Farber and Robert Costanza, "The Economic Value of Wetlands Systems," Journal of Environmental Management, Vol. 24, 1987, pp. 41-51.

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<sup>171</sup>Stephen Farber, "The Value of Coastal Wetlands for Protection of Property against Hurricane Wind Damage," Journal of Environmental Economics and Management, Vol. 14, No. 2, pp. 143-151, 1987.

<sup>172</sup>The Economic Value of Wetlands Systems," pp. 49-50.

<sup>173</sup>Survey of Current Business, Vol. 67, No. 7, July 1987. Using 1982 as a base year, the fixed weighted price indexes for GNP for 1983 and 1986 are 104.1 and 115.1 respectively.

<sup>174</sup>According to Table 7-1, the high Turner-Cahoon estimate of wetland loss due to oil and gas is 2.3812 acres per well. This figure multiplied by the 1986 well total of 10,939 yields 26,048 acres.



## **Chapter 8: Summary of Dissertation**

Hicksian income is a flow of sustainable consumption. It is the maximum value that society could actually consume between the beginning and end of a period without being worse off at the end than at the beginning, i.e., without changing the income creating potential of the capital stock, or wealth. When beginning period capital stock is diminished or its income creating potential reduced over the course of a period, Hicksian income must be adjusted downward to account for the reduced income potential. This adjustment should be the lesser of the benefits lost or the cost of replacement of the capital necessary to preserve the income potential. In accounting terms, Hicksian income is equal to actual period income minus (plus) the value of net depletion (augmentation) of the capital stock. This net change in the capital stock is measured as the discounted change in income flow generated by the change in stock.

It is well recognized that adjustments to actual period income must be made for loss of traditional, physical capital such as buildings and machinery. However, in principle, income adjustments to reflect capital depletion are just as important for environmental capital as for traditional capital. Environmental capital includes marketed and nonmarketed natural resource stocks. Both petroleum and the capacity of a wetland to provide flood protection are types of environmental capital. To the extent that economic activity depletes environmental capital, this loss should be accounted for in determination of Hicksian, or sustainable, income. Present national income measures do not adequately account for net depletion of environmental capital. Gross national product (GNP) makes no allowance for net depletion of any capital, while net national product (NNP) only subtracts an estimate of the traditional, physical capital consumed in the current production of goods and services by the business sector.

The exclusion of environmental capital depletion from national income measures may become more important with time as evidence accumulates of deterioration of

environmental capital due to human economic activity. Examples include wetland loss, ozone layer depletion, contamination of land and groundwater by toxic wastes, air pollution, and tropical rain forest destruction. This exclusion of environmental losses from measures of income may be particularly important for countries which rely heavily on natural resources for current gross income flows.

The basic problem addressed in this dissertation is the lack of any macroeconomic indicator of the sustainability of income despite increasing evidence of widespread changes in environmental capital. A solution requires a conceptual method of integrating environmental changes into the traditional economic accounts, and a method of specifying and valuing changes in environmental capital. At the conceptual level, environmental losses can be integrated into the Hicksian income framework by considering marketed and nonmarketed natural resources and environmental capital as stocks of depreciable capital in a manner analogous to traditional capital. The value of the net depletion (augmentation) of environmental capital should be subtracted from (added to) actual period income, or traditional Net National Product, to determine Hicksian income measures of sustainable income.

Difficult problems arise in attempting to implement this conceptual framework since the specification and valuation of environmental capital changes may be difficult. Even if physical changes in environmental capital are properly measured, there are major problems in attaching monetary values to these changes. There may be lags between the economic activity and the environmental effects, and the ultimate, perhaps uncertain, effects on humans and natural ecosystems. These lags and uncertainties make the calculation of the present value of environmental damages very difficult. In addition, people affected by pollution are often ignorant of the full range of environmental values so their preferences may reveal little of the true value of the environment to them. In many cases, such as ozone layer depletion, scientific knowledge itself is imperfect.

These serious valuation difficulties have led to two different approaches to the incorporation of environmental effects in Hicksian income measures.

The first approach rejects the monetary valuation of net environmental capital depletion as too speculative and simply provides disaggregated information about changes in environmental capacity linked, if possible, to economic activities in the traditional accounts (GNP). For example, physical changes in the capacity of air to assimilate industrial wastes can be measured over time and linked to major human causes. The examples of this approach examined in this dissertation are the French Natural Resource Accounts, Norway's Natural Resource Accounts, Roefie Huetting's system of environmental statistics, and Anthony Friend's Natural Resource Accounting Framework. The French system requires the most detailed physical information due to three different qualitative evaluation dimensions: economic, ecological, and sociocultural. There is no method of making tradeoffs between the three different valuation dimensions, nor between changes in different environmental parameters within one dimension. Norway's system requires less data because it considers all natural resources and environmental capital as economic resources. There are no other evaluation dimensions in their accounting system. The Norwegian accounts physically aggregate some natural resource categories. If this approach was combined with shadow values of changes in environmental capital, aggregated capital consumption allowances could be estimated. Huetting's framework concentrates on linking changes in nonmarketed environmental capital with economic activities. Although he suggests isolating environmental expenditures in GNP and measuring the monetary cost of meeting environmental standards, he does not believe that accurate shadow prices can be constructed for many environmental services. His approach is limited to the specification of physical changes in nonmarketed environmental capital. Friend's system requires a large amount of environmental statistics. These include resource stock accounts and material-energy-balance accounts. His system requires some

physical aggregation to limit the information to a feasible set. At present, his complete statistical system may be financially impossible for all but the richest countries.

These disaggregated approaches avoid the difficult task of monetary valuation of environmental capital losses. They present a wide range of disaggregated, physical effects information with no way to examine the tradeoffs between economic activity and the changes in environmental capital. This information may be of limited use to policymakers interested in assessing the capacity of the economy to develop in a sustainable manner. Policymakers may need explicit measures of tradeoffs. They would be unable to compare policies that save wetlands but reduce oil and gas production.

The second approach attempts to value the changes in environmental capital in a manner analogous to accounting for traditional capital by aggregating the environmental effects of economic activity. This method yields a single measure of a capital consumption allowance for environmental capital which can be directly incorporated in traditional income accounts. Two approaches to calculating such depreciation allowances for marketed natural resources, El Serafy, and Landefeld and Hines, were examined. Landefeld and Hines value resource depletion and treat that as a capital loss and subtract it from NNP. This is analogous to the treatment of traditional capital in the construction of capital consumption allowances. El Serafy establishes, mathematically, an infinite income equivalent of a finite income stream (from the exhaustible resource) in each accounting period. This technique allows the division of the finite income stream into two components: capital loss, an amount which must be reinvested to maintain constant real income, and income, which can be spent without lowering sustainable living standards. El Serafy's approach deducts from exhaustible resource revenues an amount which would be necessary to maintain constant real income even after the resource is exhausted. The major difference between the methods of El Serafy and Landefeld and Hines is that El Serafy would only deduct the capital loss component of net depletion in the current accounting period, whereas Landefeld and Hines would

subtract all net depletion. Both approaches are feasible with existing data on resource prices, interest rates, and reserve stocks. However, the capital consumption allowance estimates may not be as accurate as, and will certainly be more volatile than, measures of traditional capital due to new discoveries, technological changes, and interest rate volatility over time.

Henry Peskin's method of including nonmarketable environmental capital into the economic accounts was also examined. Nonmarketed natural services require estimation of shadow values. Peskin shows that these services can be valued in two ways: as environmental services, the value of the disposal services of the environment, or as environmental damages, the value of social damages from the use of the environment's disposal services. In a perfect market or perfect market simulation, environmental services and damages would be equal at the margin. Peskin places environmental services and damages into a macroeconomic accounting framework. Environmental services are deducted from NNP on the input side as a subsidy to firms. Environmental damages are subtracted from NNP on the output side as negative final goods. The subtraction of environmental damages from NNP yields a measure of sustainable income which includes the depreciation of nonmarketed environmental capital.

Two other aggregated approaches were examined: mass-energy-balance accounting and energy accounting. The fundamental design principle of the mass-energy-balance approach is the conservation of material and energy. In a closed economy (no imports or exports), the total material and the total energy extracted from the natural environment as raw material must exactly balance the total material and total energy returned to the environment as waste flows accounting for material to energy conversion, less any accumulation in the form of capital stocks and inventories. This design principle allows the mass-energy-balance accounts to trace the extraction and transformation of materials and energy from extraction through the economy and then

back to the environment as waste. Hence environmental resources can be organized in terms of mass before and after their transformation by economic activity. Since these accounts do not consider the critical economic valuation problems, it is, at best, a partial approach to the development of environmental capital consumption allowances.

Energy analysis attempts to measure marketed and nonmarketed energy flows in economic and ecological systems, and to connect energy accounting units with economic value. The embodied energy (sum of the direct and indirect energy inputs = total energy cost of a good) has been found to be correlated over time with the dollar value of output in the United States economy. The energy analysis method is based on the hypothesis that, since embodied energy and economic value to society are correlated for marketed goods, then the embodied energy in nonmarketed environmental systems can be used to estimate the value to society of the nonmarketed goods. This hypothesis is important because it may be easier to calculate the embodied energy in an ecological system than to calculate the conventional willingness to pay value. Since energy analysis has a method for conversion of energy flows to dollar values, it does allow the calculation of aggregated capital consumption allowances. However, it is uncertain that all natural resources with large amounts of energy such as hurricanes would also be valued highly by humans in a perfectly informed society. The lack of agreement over the validity of the critical hypothesis of the correlation between embodied energy and dollar value for all goods lessens the usefulness of energy analysis.

The usefulness of any aggregated approach depends on the reliability of the estimates of environmental values. Their reliability may be less than that for traditional capital because many environmental services are not marketed, and there are often long lags between the environmental change and the effect on humans. Furthermore, people may be ignorant of some environmental values, and scientists may also be uncertain of the true value of say, a wetland, to society. However, the aggregated approach does

present comprehensible information on the tradeoffs between economic activity and changes in environmental capital.

This dissertation has provided an illustrative example of an aggregated approach to the estimation of a capital consumption allowance for the loss of Louisiana wetlands environmental capital due to oil and gas economic activity. The theoretically correct measure of the capital consumption allowance is the minimum of the cost of replacing the lost services, or the social value of the benefits lost. In the absence of comprehensive data on costs, estimates are made of the current social values of wetlands lost due to oil and gas activity as a measure of the capital consumption allowance.

Two different methods were used to estimate the physical acres lost due to oil and gas activity. The first relied on wetland scientists' consensus estimates of Louisiana wetland loss due to oil and gas activity over a 24 year period (1955-1978). These data were used to estimate an average loss in acres per thousand barrels of oil-gas as well as an average loss in acres per well. This method does not explicitly allow for the lagged effects of oil and gas activity on wetland loss although the time period is so long that such lagged effects may implicitly be accounted for. It relies on consensus estimates of the range of oil and gas related losses. In addition, a time series statistical method of accounting for wetland loss due to oil and gas activity was used to estimate the physical impact of oil and gas activity on Louisiana wetlands. Three different mathematical specifications of annual wetland loss functions (linear interpolation, linear regression, and exponential regression) for the period of 1955-1986 were estimated. Annual wetland losses estimated from these functions were then used as dependent variables in regressions with independent variables reflecting annual oil and gas activity in Louisiana. This method provided a measure of the marginal effect of, say, another well drilled, on current and future wetland losses. The statistical method's primary defect is an omitted variable problem. There are no data available for estimating the wetland

losses due to other factors, particularly the diversion of Mississippi river sediments from wetlands to the Gulf of Mexico. These factors are highly correlated with levels of oil and gas activity over time, and their omission will bias upward the estimate of losses due to oil and gas activity. The estimates of oil and gas induced wetland loss for 1986 were similar for both the consensus and statistical methods. This similarity provides some support for the validity of the results.

The estimated physical losses from oil and gas were combined with two different estimates of per acre wetland values based on different valuation methods: willingness to pay and energy analysis. The willingness to pay method considers wetland values as the sum of the value of the separate services of commercial fishing and trapping, recreation, and storm wind damage protection. This value is incomplete because some important values, such as flood protection and waste treatment, have not been included. The per acre values ranged from \$648.73 to \$3076.54 depending on interest rates assumed. The second evaluation method, energy analysis, measures the total energy captured by natural economic systems and assigns an economic value to that energy. Since it includes all energy captured by natural systems, regardless of whether it is currently valued by humans, this method may provide an upper bound to the wetlands valuation. This estimate of per acre values ranged from \$11,722 to \$31,254 depending on interest rates assumed.

The wetland loss and per acre values together yield estimates of the capitalized environmental loss to Louisiana and the United States of 1986 oil and gas activity in the Louisiana Coastal Zone. Depending on whether barrels of oil and gas or completed wells was the measure of oil and gas activity, the consensus estimates of the capital consumption allowance (CCA) using willingness to pay ranged from \$21.453 (barrels) to \$40.749 million (wells) at a 3% discount rate and from \$4.524 (barrels) to \$8.592 (wells) million at an 8% rate. The range of CCA estimates using the energy analysis method



was from \$217.934 (barrels) to \$413.959 (wells) million at 3% and from \$81.738 (barrels) to \$155.258 (wells) million at 8%.

The range of estimates of capital consumption allowances using the statistical method is similar to the consensus method. Depending on whether barrels of oil and gas or completed wells was the independent variable, the statistical estimates of the CCA using willingness to pay ranged from \$18.185 (barrels) to \$66.207 (wells) million at 3% and from \$3.774 (barrels) to \$13.961 (wells) million at 8%. The range of CCA estimates using the energy analysis method was \$184.742 (barrels) to \$672.586 (wells) million at 3% and \$68.199 (barrels) to \$252.257 (wells) million at 8%.

The final monetary, environmental capital consumption allowances due to the oil and gas activity may not be very accurate due to inadequate data for other important causal mechanisms of wetland loss. Also, incomplete accounting for all wetland values using the willingness to pay method, and uncertainty as to the validity of the energy analysis estimates, contribute to measurement inaccuracy. However, this dissertation's estimates of capital consumption allowances indicate the type of procedure necessary to estimate the net depletion of environmental capital due to current economic activity.

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## Vita

GEORGE EDWARD FOY JR.

- PERSONAL:**      Citizenship: U.S.A.  
Date and Place of Birth: June 8, 1957, Charleston, South Carolina
- ADDRESS:**      Home:      Office:  
Post Office Box 16508      Department of Economics  
Baton Rouge, LA 70893      2138 CEBA  
(504) 766-1776      Louisiana State University  
Baton Rouge, LA 70803-6306  
(504) 388-3805
- EDUCATION:**      Ph.D. (expected, May 1989) in Economics, Louisiana State University  
M.S. (May 1986) in Economics, Louisiana State University  
B.A. (May 1979) in Economics, Yale University  
  
Specialized fields of graduate study are natural resource economics, industrial organization and regulation, and political philosophy.
- TEACHING EXPERIENCE:**      1985-1989  
Macroeconomic Principles      (4 semesters)  
Microeconomic Principles      (2 semesters)  
Macro/Microeconomic Principles      (2 semesters)  
Applied Resource Economics      (part-time)  
Econ. of Population and Environment      (part-time)
- TEACHING AWARDS:**      1988-89 Excellence in Teaching Award, Economics Department, Louisiana State University.  
  
1988-89 Outstanding Teaching Award, College of Business Administration, Louisiana State University.
- RELATED EXPERIENCE:**      Summer 1988  
Consultant, World Bank: Research on environmental/economic problems in selected Latin American and Caribbean countries: Haiti, El Salvador, Costa Rica, and Brazil.  
  
1979-1984  
Officer of Meadowcreek Project, a 501 (c) (3) nonprofit organization established in 1979 for education and research in applied ecology, agriculture, renewable energy systems, and forestry, as well as the ethical, social, economic, and political aspects of sustainability.

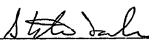
**DOCTORAL EXAMINATION AND DISSERTATION REPORT**

**Candidate:** George E. Foy Jr.

**Major Field:** Economics

**Title of Dissertation:** Toward the Inclusion of Environmental Factors in the Concept and Measure of National Income

**Approved:**

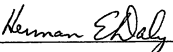
  
Major Professor and Chairman


  
Dean of the Graduate School

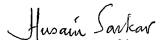
**EXAMINING COMMITTEE:**

  
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**Date of Examination:** March 28, 1989

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