ENVIRONMENTAL ECONOMICS AND GLOBAL WARMING

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Summary

The changing nature of environmental impacts of development processes has forced a reexamination of the basic premises of economic theory in general, and environmental economics in particular. Faced with problems of global warming and tragedy of the commons,we are especially concerned with the development processes that are sustainable with respect to the natural environment and are within the market economy. We examine theoretical frameworks for analyzing intertemporal optimality and intergenerational equity, and elaborate on dynamic models with social overhead capital.

1. Introduction

1.1 Two International Conferences on the Environment

The accelerated pace of economic activities, industrial, agricultural, urban, and otherwise, in the last five decades has substantially altered the delicate balance between the environment and human activities. During the last three decades, in particular, we have also seen a significant change in the nature of social, economic, and cultural impacts for the natural environment during the process of economic development. This is symbolically illustrated by the agenda of two international conferences convened by the United Nations–the Stockholm conference in 1972, on the one hand, and the Rio Conference in 1992, on the other.

The Stockholm Conference was primarily concerned with the degradation of the natural environment and ensuing health hazards caused by the processes of industrialization during the 1960's. The degradation of the natural environment was mainly caused by the emission of chemical substances such as sulphur and nitrogen oxides which themselves are toxic and hazardous to both human health and biological environments. In the Rio Conference, on the other hand, the main agenda concerned the degradation and instabilization of the global environment, such as global warming, the loss of bio-diversity, decertification, etc., that are the results of the intensified industrialization and extended urbanization. They are primarily caused by the emission of carbon dioxide and other chemical substances which by themselves are not harmful to the natural environment nor hazardous to human health, but at the global scale causes the atmospheric instability and other serious environmental disequilibria.

1.2 Economic Theory and the Environment

The changing nature of environmental impacts of processes of economic development has forced us to reexamine the basic premises of economic theory in general and environmental economics in particular, and to search for the theoretical framework where the mechanisms through which the natural and social environments are interwoven with processes of industrialization and urbanization are closely analyzed and their social policy implications are explicitly brought out. We are particularly concerned with the processes of economic development that are sustainable both with respect to the natural environment and within the market economy, and with analyzing the institutional arrangements and policy measures under which the processes of sustainable development may necessarily ensure. Such institutional arrangements are generally defined in terms of property right assignments to various natural resources, with specific reference to the behavioral criteria for those social institutions and organizations that manage various natural and common resources.

One of the obvious implications of the changing nature of the environmental impacts upon economic processes in the last three decades is that economic incentives on the part of individual members of the society are primarily relied upon, and direct social control or coercion are neither effective in solving global environmental problems nor desirable from social and cultural points of view.

The primary policy instruments now are those of environmental taxes, such as carbon taxes, or some other form of pricing scheme where market institutions in a broader sense may be effectively brought in to play the allocative mechanism. The reliance upon market institutions and private incentives, however, may occasionally bring about unstable and socially unjust outcomes with regard to the distribution of income, both nominal and real. It has particularly undesirable consequences regarding processes of economic development for developing nations, occasionally resulting in a decisive widening of the gaps between developed and developing nations.

The impact of the degradation of the global environment is most painfully felt by developing nations, because it is the agriculture and related sectors of the economy that are most sensitively affected by changes in climatic and ecological conditions. For that matter, institutional and policy measures intended to remedy the degradation of the environment also are most likely to adversely affect developing nations or those whose income levels are low. Traditional economic theory is not particularly well suited to handle these problems that are primarily concerned with distributional equity and ethics, both intergenerational and international.

2. Global Warming

During the past two decades, meteorologists, geophysicists, and geochemists have continuously warned us about the existence of numerous symptoms which indicate that the atmospheric equilibrium is seriously disturbed on a global scale. Global warming is one of these symptoms that holds enormous implications for virtually every aspect of human life on Earth, affecting not only the current generation, but also all future generations.

The phenomenon of global warming may be best indicated by the global average surface air temperature, which has continuously risen over some two hundred years since the Industrial Revolution, with an accelerated pace in the last two decades. According to the report issued by the Intergovernmental Panel on Climate Change (IPCC), the global average surface air temperature would most likely be 3°~4°C higher than the present level by 2100, 4°~5°C higher than the pre-industrial level. This is a disturbing phenomenon if we take note of the fact that the global average surface air temperature had risen only 0.7°C over some 10,000 years since the end of the last Ice Age to the time of the Industrial Revolution.

An increase in the global average surface air temperature of such magnitude will bring about alarming changes in rainfall patterns and other climatic conditions, resulting in serious ecological disequilibrium. One of the most conspicuous outcomes would be a rise in sea levels. The IPCC report predicts that sea levels will rise 20 cm by 2030 and 45 cm by 2070. A rise in the sea level on the order of 20-45 cm will have an almost catastrophic impact upon human life, since the majority of human settlements are located either near the seashore or by rivers. It is estimated that about half a billion people would be directly affected by such an increase in the sea level.

The strength and frequency of hurricanes and typhoons would also intensify and the distribution of rainfall would become more unstable. Climatic changes accompanied by global warming would become more unstable. Climatic changes accompanied by global warming will cause hardships, particularly on farmers and fishermen, because the choice of crops and the mode of cultivation have been adjusted to suit climatic and soil conditions slowly over many years and the availability of fish is delicately correlated with the natural environment. Tropical or sub-tropical climatic conditions would spread further to the north (or the south for those in the Southern Semi-sphere), thus disseminating the danger of tropical diseases and insects.

The principal causes of global warming as described above are atmospheric concentrations of radiative forcing agents, which keep infrared radiation from Earth's surface and warm the surface air temperature. The radiative forcing agents, often referred to as "greenhouse gases", are identified as water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCS), among others.

A particularly important role is played by carbon dioxide. If carbon dioxide did not exist in the atmosphere, the global average surface air temperature would be –18°C, thus making life on Earth virtually impossible. On the other hand, an excess concentration of atmospheric carbon dioxide would warm the globe significantly. It is estimated that the planet Venus, which has a high atmospheric concentration of carbon dioxide, has a surface temperature of about 470°C.

The atmospheric concentration of carbon dioxide has increased from the level of 280 ppm (ppm = part per million) at the time of the Industrial Revolution to the current level of 360 ppm. Most reliable estimates since 1958 have been made at Mauna Loa and the South Pole, indicating that the atmospheric concentration of carbon dioxide has increased at an annual rate of 1.3 ppm from 1958 to 1988, as compared with an annual rate of 0.3-0.5 ppm from 1880 to 1958. If the current trend were to persist, it would reach the level of 560 ppm by 2070, double the pre-Industrial level, and the resulting equilibrium warming would be 2.5°-4.5°C higher than the current level.

The atmospheric concentration of carbon dioxide is largely of anthropogenic origin, primarily caused by the burning of fossil fuels. The depletion of tropical rain forests also has become another major source of the atmospheric concentration of carbon dioxide in the last three decades, now estimated to be responsible for one-third of those emitted by the combustion of fossil fuels.

The mechanism by which the anthropogenic emissions of carbon dioxide disturb the atmospheric equilibrium may be best understood if we draw a crude picture concerning the global carbon cycle.

There are three major reservoirs of carbon on Earth's surface, each roughly of the same capacity: the atmosphere, the surface ocean (to a depth of 75m), and the terrestrial bio-sphere, respectively containing 700 GtC, 700 GtC, and 800 GtC (GtC. refers to Giga = 10^9 tons of carbon). Land planets in detritus contain a much larger quantity of carbon, roughly of the magnitude of 3,000 GtT. The exchange of carbon between the atmosphere and the surface ocean is approximately in equilibrium, exchanging 90-100 GtC annually. The terrestrial bio-sphere absorbs atmospheric carbon dioxide through the process of photosynthesis, at about 60 GtC annually. Roughly the same quantity of carbon dioxide is released into the atmosphere through the processes of decomposition and respiration. Thus the exchange of carbon dioxide between the atmosphere and the terrestrial bio-sphere is also in equilibrium. Prior to the Industrial Revolution, whatever the residual differences existed in the exchange of carbon between the three reservoirs had been delicately balanced by the eruption of volcanoes and other natural phenomena.

The stability of the global carbon cycle began to be disturbed by the massive consumption of fossil fuels, particularly of coal and oil, which characterized the new technologies brought about by the Industrial Revolution. The combustion of fossil fuels now emits 6 GtC of carbon dioxide annually. This has an important implication for the stability of the global carbon cycle. While the cycle on the Earth's surface takes place within a period of 10 to 100 years, fossil fuels are made of plants and animals that used to live on Earth's surface some several hundred million years ago and are not being extracted at an extremely high pace.

Of the 6 GtC of carbon dioxide annually emitted into the atmosphere, the largest contributor is the United States (24%), followed by the former Soviet Union (20%), China (9%), and Japan (5%). These four countries contribute close to two-third of the world total. However, it should be borne in mind that the quantity of carbon dioxide emitted by the combustion of fossil fuels per GNP varies a great deal among the countries. The Japanese figure is roughly half that of the United States, suggesting a rather significant degree of substitutability for energy use.

The stability of the global carbon cycle has been also disturbed by the massive depletion of land forests, particularly of tropical rain forests, in the last three decades. Total acreage of land forests is estimated at about 4 billion hectares, including open and closed forests and woodlands. According to the estimate made by the World Resources Institute, the acreage of tropical rain forests annually lost is now 160-240 million hectares [World Resources Institute (1991)], a magnitude much higher than the previous estimate of 110 million hectares made by the FAO for 1980. It is estimated that 0.4-2.6 GtC of carbon dioxide are released into the atmosphere due to changes in the pattern of land use, about 95% of which is regarded as the result of deforestation of tropical rain forests.

Carbon dioxide is now estimated to be responsible for 55% of the greenhouse effect, whereas methane accounts for 15%, nitrous oxide for 6%, and CFCs for 24%. Among these greenhouse gases, CFCs are solely of anthropogenic origin, introduced for the first time during the 20^{th} century. CFC-12 and CFC-11 are the most common CFCs with atmospheric concentrations respectively of 484 ppt and 280 ppt (ppt = parts per trillion). However, they have a powerful greenhouse effect, estimated to be 20,000 times more powerful than carbon dioxide.

CFCs also tend to remain in the atmosphere for a long period and are also responsible for the destruction of the ozone layer. In view of the eminent danger to which CFCs have exposed us, an international agreement was reached in 1987. The Montreal Protocol to Control Substances that Deplete the Ozone Layer stipulates a substantial reduction and the eventual abolishment of the production and use of CFCs.

Since the phenomenon of global warming has been scientifically established and has become a focal issue from the economic, social, and political points of view, a number of international conferences and negotiations have been held by various governments and international agencies, some of which possess particularly important implications for arresting global warming.

Governmental negotiations, however, mostly have the common trait that they try to agree upon a certain scheme whereby each country is obliged to curtail emissions of greenhouse gases to certain levels, typically as percentages of current emission levels, and then to try to implement that commitment through administrative or similar measures. Such an administrative scheme is generally difficult to implement within a decentralized, entrepreneurial framework, occasionally resulting in an inefficient allocation of scarce resources, particularly in terms of the provision of an incentive scheme for energy-saving technological innovations or for alternative energy sources.

We search for policy and institutional measures that will effectively arrest the process of global warming and the at the same time bring about the intertemporal allocation of scarce resources, including both private means of production and environmental quality, (particularly the atmospheric composition), that is intergenerationally equitable in terms of the intertemporal preference ordering prevailing in the society.

3. Global Warming and Economic Theory

The phenomenon of global warming is basically of anthropogenic origin, primarily due to the massive consumption of fossil fuels and secondly due to the depletion of tropical rain forests. The predominant forces behind these human activities are economic, and any policy or institutional measures to effectively arrest the process of atmospheric disequilibrium would have to take into account the economic, social, and political implications.

There exist two distinct features in the phenomenon of global warming that traditional economic theory is hardly equipped to deal with. First, global warming is caused by unstable concentrations of carbon dioxide and other greenhouse gases in the atmosphere. The atmosphere plays the role of social overhead capital, that is neither privately appropriated nor subject to transactions in the market. Traditional economic theory has been almost exclusively concerned with those scarce resources that are privately appropriated and whose ownership rights are transacted on the market.

The second feature concerns the equity problem between different generations and between different countries. Those who emit most of the carbon dioxide are those who benefit most from the combustion of fossil fuels, while those who suffer most from global warming are those who benefit least from the emission of carbon dioxide.

By the same token, while the current generation enjoys a spuriously high living standard from the combustion of fossil fuels, future generations will have to suffer from global warming and other problems related to the atmospheric concentrations of carbon dioxide and other greenhouse gases. Again, traditional economic theory has shied away from problems involving equity and justice, restricting its realm to the efficiency aspect, with notable exceptions of the works by Arrow, Atkinson, Dasgupta, Sen and others.

Thus the problem of global warming offers us a unique opportunity to reexamine theoretical premises of traditional economic theory and to search for a theoretical

framework that enables us to analyze the dynamic and equity problems involving environmental disruption. Such a framework is provided by the theory of optimum economic growth and the theory of social overhead capital, both of which have been developed in the last three decades. In particular, the dynamic theory of environmental economics, as developed by Karl-Göran Mäler and William Nordhaus, gives us the basic framework that can be used to analyze the economic and political circumstances under which global warming and other environmental problems occur and to find the policy and institutional arrangements to effectively arrest them. Mäler's and Nordhaus's theory concerns finding the pattern of intertemporal allocation of scarce resources where the optimum balance between environmental quality and economic growth is attained, with the concept of imputed price playing a central role.
The concept of imputation was originally introduced by Carl Menger in his attempt to construct modern economic theory and since then it has served as one of the basic concepts in price theory.

Menger was first concerned with the problem of imputing the subjective utility value to various types of consumption goods that contribute to generate such a value. Under the Mengerian assumption of cardinal utility, the imputed price of each consumption good becomes equal to its marginal utility. The consumer optimum then is attained, if and only if, the imputed price of each consumption good is proportional to the market price.

Menger than proceeds to extend the concept of imputed price to productive activities. The imputed price of a factor of production is equal to the marginal value product of that factor of production, and the producer optimum is attained if, and only if, the imputed price of each factor of production is equal to the market price.

Menger's theory of imputation, however, was static, without taking the time element into explicit consideration. Contributions in the theory of optimum economic growth, particularly those of Ramsey, Uzawa, Koopmans, Cass, Srinivasan, and others, have extended the concept of imputed price to the dynamic situation where one inherits accumulating impacts from past human activities and tries to choose the current economic activities with the interest of all future generations explicitly taken into account. The phenomenon of global warming is precisely the kind of dynamic problem where the modern theory of imputation is aptly applied, as effectively explored by Mäler and Nordhaus.

The first major work in incorporating the environment into economic theory was done by Alan Kneese and his associates at Resources for the Future in the early 1960s. They succeed in constructing an analytical framework in which the flow and circulation of all natural resources and materials in processes of economic activities are fully accounted for and the interactions with economic activities are effectively analyzed. Their theoretical construct was a generalization of the Arrow-Debreu model of general equilibrium to one in which the natural environment was integrated into standard economic theory. The Kneese model of environmental equilibrium, however, was largely confined to the static circumstances, with dynamic implications only tangentially noted. This is primarily due to the fact that a systematic theory of economic dynamics was not yet fully developed then.

Beginning in the middle 1960s, various attempts have been made to develop full-fledged dynamic analysis for both decentralized and centralized economies. Karl-Göran Mäler was the first to apply the techniques of optimum economic growth theory to formulate a systematic, dynamic model where the environment was made an integral component of processes of economic development. Mäler then analyzed the patterns of intertemporal economic activities that are dynamically optimum in terms of the intertemporal preference ordering induced by a Ramsey-Koopmans-Cass utility integral, where effects of environmental degradation upon the schedules of marginal utilities and marginal products of private factors of production are fully taken into account. Since then a large number of studeis have been made to apply Mäler's theory of optimum environmental quality to more specific cases such as forestry resources, subterranean water, coastal wetlands, and fisheries commons.

As was emphasized previously, a distinct feature of the atmosphere is that it is neither privately appropriated, nor is it subject to transactions on the market. Thus the atmosphere may be regarded as a component of social overhead capital, and some of more relevant propositions in the theory of social overhead capital may be applied to examine institutional arrangements for the stabilization of the atmospheric composition.

The concept of social overhead capital was originally introduced by Uzawa in 1974, where the mechanisms by which social overhead capital interacts with the working of market institutions are explicitly brought out and the effects of social overhead capital on the distribution of real income are briefly analyzed. Since then the concept of social overhead capital has been extended by Uzawa to include the natural environment, social infrastructure, and institutional capital, to explicitly analyze the phenomena of externalities, both static and dynamic, and to examine the implications for the structure of intertemporal allocation of scarce resources that is dynamically optimum.

The dynamic analysis of global warming is based upon some of the recent studies in the theory of social overhead capital and the theory of optimum dynamics. The simplest version of the analysis was first introduced by Uzawa, and initially the primary concern was with the problems related to global warming in the Pacific Rim region, but the accumulation of private capital and changes in the size of population have not been explicitly brought into the initial analysis. It is possible to take into account the implications of the accumulation of private capital and changing population for the process of dynamic imputation, and to extend the analysis to cover the world as a whole, with the basic tenor of the conclusions remaining intact.

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Biographical Sketch

Professor Hirofumi Uzawa, now at the Japan Academy, is one of the outstanding economic theorists of the twentieth century. His pioneering and definitive contributions have enriched the theories of Walrasian equilibrium, stability and economic growth.