



## The not so worldly philosophers: why mainstream economics can't be green

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### **Abstract**

*The economic theory that serves as the basis for coordinating economic activities in the global market system and for implementing economic solutions for environmental problems is neoclassical economics. In economic textbooks, the creators of this theory are credited with transforming the study of economics into a rigorously mathematical scientific discipline. But what is not widely known is that neoclassical economic theory was created by substituting economic constructs derived from classical economics for physical variables in the equations of a soon-to-be outmoded mid-nineteenth century theory in physics. The mathematical formalism that resulted from these substitutions was predicated on unscientific axiomatic assumptions that remained essentially unchanged in subsequent extensions and refinements of neoclassical economic theory. And this explains why the mathematical formalism used by contemporary practitioners of neoclassical economic theory effectively precludes the prospect of implementing scientifically viable economic solutions for a broad range of very menacing environmental problems.*

**Key words:** Neoclassical economics; invisible hand; global warming; two culture problem.

An article on the editorial page of *The New York Times* attributed the regulatory failure that resulted in the global financial crisis in the fall of 2008 to the "...Bush administration's magical belief that the market, with its invisible hand, works best when it is left alone to self regulate and self correct."(1). What the editorial failed to mention is that this "belief" is the central legitimizing principle in the economic theory that serves as the basis for coordinating economic activities in the global market system-- neoclassical economics. Virtually all mainstream economists are practitioners of this theory, and this list includes the economists who developed the Bush administration's \$700 billion Economic Stimulus Plan and the Obama administration's \$789 billion American Recovery and Reconstruction Plan. The fundamental assumption in these bailout plans is that the global economic crisis exists because the self correcting and self regulating dynamics of market systems associated with the "invisible hand" ceased to function properly. And the intent of these plans is to create market conditions in which these dynamics can regain their proper functioning through a massive infusion of capital generated by deficit spending.

In economic textbooks, the creators of neoclassical economic theory are credited with disclosing the lawful

dynamics of market systems and transforming the study of economics into a rigorously mathematically scientific discipline. But what these textbooks fail to mention is that neoclassical economic theory was created by substituting constructs derived from classical economics for physical variables in the equations of a mid-nineteenth century theory in physics (2).

A number of physicists told the economists that the economic constructs were utterly different from the physical variables and there was no rational basis for making the substitutions. But the economists apparently failed to comprehend how devastating this criticism was and proceeded to claim that they had transformed the study of economics into a scientific discipline comparable to physics. As it turned out, the origins of neoclassical economic theory in mid-nineteenth century physics were soon forgotten and the claim that neoclassical economic theory is scientific was almost universally accepted.

At this point, it is important to emphasize that it is not my intention to launch an ill mannered attack on the moral or intellectual integrity of mainstream economists. Obviously, there is nothing wrong with using complex mathematical formalism to model tendencies to occur in economic

reality and the formalism used by the practitioners of neo-classical economic theory provides a reasonably coherent basis for coordinating economic activities in market systems. But as this discussion will demonstrate, this theory can no longer be viewed as useful in even strictly pragmatic or utilitarian terms because it fails to meet what must now be viewed as the fundamental criterion for the usefulness of any economic theory- the extent to which the theory allows economic activities to be coordinated in environmentally responsible ways.

I posit that one reason why neoclassical economic theory cannot pass this test relates to its little known and rarely discussed origins in mid-nineteenth century physics. After the creators of neoclassical economic theory substituted the economic constructs for the physical variables in the equations borrowed from physics, the resulting mathematical formalism was predicated upon unscientific axiomatic assumptions. Subsequent generations of mainstream economists extended and refined this formalism, but this failed to result in any substantive changes in the axiomatic assumptions (3).

While this may seem like a rather esoteric intellectual problem, it has some devastating real-world consequences for the following reason- the unscientific assumptions in neoclassical economic theory obviate the prospect of implementing scientifically viable economic solutions for global warming and other menacing environmental problems. Understanding why this is the case requires some familiarity with the origins and transformations of the construct of the “invisible hand” in the history of mainstream economic theory.

### ***The Not So Worldly Philosophers***

The eighteenth century classical economic theorists (Adam Smith, Thomas Malthus, and David Ricardo) were moral philosophers who participated in, and were greatly influenced by, a widespread philosophical and religious movement known as Deism. The fundamental impulse of this movement was to make belief in the existence of God consistent with the implications of the mechanistic worldview of Newtonian physics. Since this physics assumes that physical laws determine the current and future states of physical systems, the Deists concluded that the universe does not require, or even permit, active intervention by a deity after the first moment of creation. They then imaged the deity as a clockmaker and the universe

as a clock regulated and maintained after its creation by physical laws.

The philosophers we now regard as classical economists assumed that the deity created two sets of laws to govern the workings of the clockwork universe- the laws of Newtonian physics and the natural laws of economics (4). Based on this assumption, they claimed that the natural laws of economics govern decisions made by economic actors in much the same ways that Newtonian laws of gravity govern the movements and interactions of material objects. This allowed the classical economists to argue that these natural laws manifest as forces that govern the behavior of economic agents and maintain order and stability in market systems even if the actors are completely unaware that this is the case. Adam Smith referred to these forces as an “invisible hand” and this hand, in his view, was that of the providential but absentee deity (5).

In *Wealth of Nations*, Smith said that the invisible hand is analogous to the invisible force that causes a pendulum to oscillate around its center and move toward equilibrium, or a liquid to flow between connecting chambers and find its own level. Based upon this analogy, Smith claimed that this unseen hand is the force that moves independent actors in pursuit of different values toward the equalization of rates of return, and accounts for the tendency of markets to move from low to high returns. Given that Smith’s invisible hand has no physical content and is an emblem for something postulated but completely unproven and unknown, we must question why he assumed that it actually exists. The answer is that Smith was a Deist and his belief in the existence of the invisible hand was an article of faith.

The physical theory that contained the equations the neo-classical economists ( e.g.- Stanley Jevons, Leon Walras, Maria Edgeworth, and Vilfredo Pareto) used as a template to develop their mathematical models emerged from the 1840s to the 1860s. During this period, physicists generated numerous hypotheses about matter and forces in an effort to explain the phenomena of heat, light, and electricity. In 1847 Hermann-Ludwig Ferdinand von Helmholtz, one of the best known and most widely respected physicists at this time, posited the existence of a vague and ill-defined field of energy that could unify these phenomena. This served as the catalyst for the so-called “energetics” movement in which physicists attempted to account for diverse physical phenomena in terms of a unified and protean field of energy that fills all space. In an

effort to explain how this vaguely defined system could somehow remain the same as it undergoes changes and transformations, the physicists appealed to the conservation of energy law which states that the sum of kinetic and potential energy in a closed system is conserved (2).

The strategy used by the creators of neoclassical economic theory was as simple as it was absurd- they wrote down the equations of the theory in physics and substituted constructs derived from classical economics for the physical variables. Utility, a measure of economic satisfaction and well being, was substituted for energy, the sum of utility for potential energy, and expenditure for kinetic energy. In the resulting mathematical formalism, it was assumed that economic actors move and interact within a field of energy that fills all space, that the natural laws of economics operate within this field, and that forces associated with these laws legislate any and all decisions made by the actors.

Since the physical system described in the theory in physics was closed, the economists assumed that the market system described in their economic theory was closed. This was the origins of the assumption in neoclassical economic theory that market systems exist in a domain of reality that is separate and distinct from the external environment. And since the sum of energy in the theory in physics was conserved, the economists assumed that the sum of utility must be conserved. What these economists apparently failed to realize is that the sum of income/utility in an economic system is not conserved, and the conservation principle is quite meaningless in any real economic process. Nevertheless, this assumption is foundational to neoclassical economic theory in its present form--constrained maximization in general equilibrium theory.

In an effort to justify the claim that utility is conserved, the economists argued that production and consumption of goods and commodities are physically neutral processes that do not alter the sum of utility. They did so appealing to what was then regarded as a self-evident truth in the physical sciences- the law of the conservation of matter. Since this law states that matter cannot be created or destroyed, the economists claimed that the production of goods and commodities does not alter or change the immutable stuff from which they are made. They then proceeded to argue that any value accrued as a result of production and consumption must reside in the mental space of the economic actors.

This was the origin of two additional assumptions that are foundational to neoclassical economic theory. The first is that economic actors interact within a field of force (utility) in which the natural laws of economics legislate over their economic decisions and determine the value of goods, commodities, and services. The second is that the value of these goods, commodities, and services circulates in this field as capital in a closed loop from production to consumption.

This strange marriage between economic thought and mid-nineteenth century physics helps to explain why neoclassical economic theory is predicated on the following assumptions:

- The market is a closed circular flow of capital between production and consumption without inlets or outlets.
- Market systems exist in a domain that is separate and distinct from the external environment.
- The natural laws of economics, if left alone, will ensure that market systems will perpetually grow and expand.
- The unimpeded operations of the natural laws of economics will result in the perpetual expansion of national economies and the global market system.
- Environmental problems result from market failures or incomplete markets.
- The natural laws of economics can resolve environmental problems via price mechanisms, more efficient technologies, and production processes.
- Inputs of raw materials into the closed market system from the external environment are “free” unless or until costs associated with their use are internalized within the system.
- The resources of nature are largely inexhaustible, and those that are not can be replaced by other resources or by technologies that minimize the use of the exhaustible resources or rely on other resources.
- The costs of damage to the external environment by economic activities must be treated as costs that lie outside the closed market system, or as costs which are not included in the pricing mechanisms that operate within these systems.
- These costs can be internalized in the closed market system with the use of shadow pricing and the establishment of property rights for environmental resources and amenities.
- Biophysical limits do not impede the growth of market systems.

One does not have to be a scientist to realize that these assumptions make no sense at all in scientific terms. In these terms, markets are open systems that are embedded in and interactive with the global environment, and there is a definite relationship between economic activities and the state of this environment. Natural resources are clearly exhaustible and our over-reliance on one of these resources, fossil fuels, could soon result in irreversible large-scale changes in the climate system. The natural environment is not separate from economic processes, and wastes and pollutants from these processes are already at levels that threaten the stability and sustainability of virtually all environmental sub-systems. Last but not least, the limits to the growth of the global economy in biophysical terms are real and inescapable, and the assumption that market systems can perpetually expand and consume more scarce and nonrenewable natural resources is utterly false (4).

### ***A Green Thumb on the Invisible Hand***

Mainstream economists who specialize in developing economic solutions for environmental problems are known as environmental economists, and this sub-discipline in neoclassical economics is taught in universities and practiced in government agencies and development banks. Because neoclassical economic theory is predicated on the assumption that functional market economies must grow or expand, environmental economists presume that the health of these economies is sensitive to, and dependent upon, the consumption of increasingly larger amounts of environmental resources. And because the theory is also predicated on the assumption that market systems exist in a domain of reality distinct from the external natural environment, environmental resources outside of this domain are viewed as “goods, services and amenities” that are not subject to the pricing mechanisms that operate within these systems.

When environmental economists calculate the environmental costs of economic activities, they assume that the relative price of each bundle of an environmental good, service, or amenity is equivalent to the “real marginal values” of the consumer. In the mathematical formalism used by these economists, a marginal value essentially represents how much a consumer is willing to pay to acquire more of something else. The following is a description of the dynamics of this process by environmental economists Henry, Shogren and White:

“...the power of a perfectly functioning market rests in its decentralized process of decision making and exchange; no omnipotent planner is needed to allocate resources. Rather, prices ration resources to those that value them the most and, in doing so, individuals are swept along by Adam Smith’s invisible hand to achieve what is best for society as a collective. Optimal private decisions based on mutually advantageous exchange lead to optimal social outcomes.”(6).

In environmental economics, the presumption that optimal private decisions “based on mutually advantageous exchange” lead to optimal social outcomes for the state of the environment is a primary article of faith. Environmental economists assume that these outcomes will occur when the optimal private decisions determine the “right price” of environmental goods and services. The “right price” in neoclassical economic theory is a function of the prices that economic actors have paid, or are willing to pay, to realize some marginal benefits of environmental goods and services. This explains why much of the work of environmental economists is devoted to estimating the environmental costs of economic activities in these terms. This view of right prices also explains why the term “environmental externalities” has a rather peculiar meaning in neoclassical economic theory.

Externalities are situations in which the production or consumption of one economic actor affects another who did not pay for the good produced or consumed, and externalities are viewed as either negative or positive. For example, environmental economists often cite pollution as an example of the former and preservation of biological diversity as an example of the latter. When these economists use the phrase “environmental externalities,” they are referring to environmental goods and services that are “external” to market systems in the sense that they are presumed to exist outside of the domain in which the allegedly lawful dynamics of these systems operate.

Environmental economists often use cost: benefit analysis to place a value on environmental externalities, and the results of these analyses have significantly influenced public policies that address environmental issues. The problem that these accounting procedures are intended to resolve is that the only “real marginal values” that can be conferred upon the environment are determined by forces associated with the natural laws of economics that only operate within closed market systems. Given that much

of the damage to the natural environment caused by economic activities cannot be valued in these terms, environmental economists have developed indirect methods that are designed to estimate the “use-value” of these resources (7).

Contingent valuation methods have been used to assess the use-value of recreation, scenic beauty, air quality, water quality, species preservation, bequests to future generations, and other non-market environmental resources. Such methods are intended to assess the willingness-to-pay function of economic actors who would prefer to preserve natural environments (i.e.- preservation or existence values), maintain the option of using natural resources (i.e.- option values), and bequeath natural resources to future generations (i.e.- bequest values) (8). Most contingent valuation surveys seek to determine both the maximal amount that individuals are willing to pay for an increased quality of an environmental resource and the minimal amount they are willing to accept as compensation to forgo this increase.

For the sake of argument, let us assume that contingent valuation studies are capable of fully revealing maximal social outcomes of environmental policy decisions. Are we then to believe, as one such study suggested, that reduction in chemical contaminants in drinking water was not important in economic terms because the value of a statistical life associated with a reduction in risk of death in thirty years was only \$181,000 (9)? Is \$26 a measure of the real marginal costs of pollution because this is the average price that a household is willing to annually pay for a 10 percent improvement in visibility (in eastern U.S. cities (10). Is the value of whooping cranes the \$22 per year average that one set of households was willing to pay to preserve this species (11), and the value the bald eagle the \$11 per year average that another set of households would spend to preserve this apparently less valuable species (12)?

### **Mainstream Economics and the Post Kyoto Agreement**

Most of the commentary on the failure of the international community to resolve problems in the global environment places the blame on the usual suspects- the greed of international corporations, the benighted environmental policies of the Bush administration, and the inability of prosperous nations to empathize with the plight of poorer countries. But the principal barrier to resolving this crisis

is not the usual suspects. It is the failure to realize that unscientific assumptions in neoclassical economic theory effectively preclude the prospect of implementing scientifically viable economic solutions.

Scientific evidence may play a supportive and enabling role in the process of forging international agreements intended to resolve problems in the global environment, but only as a minimum condition for serious consideration of an environmental issue. What is not well known is that these agreements have made a mockery of scientifically viable solutions. In the majority of negotiations on issues such as commercial whaling, hazardous waste trade, loss of biodiversity, conditions in the Antarctic, and ocean dumping of radioactive waste, the scientific evidence was not given serious consideration. When this evidence was perceived as a direct threat to the relative economic interests of particular nation-states, it was either systematically ignored or explicitly rejected by representatives of these states.

The unfortunate result is that the Framework Convention on Climate Change (1992) failed to protect the climate system, the Convention on Biological Diversity (1992) did not even begin to reduce losses in biodiversity, and the Convention to Combat Desertification (1994) did not slow, much less reverse, this process. Similarly, the Convention on the Law of the Sea (1982) and a host of other international agreements that were intended to reduce ocean pollution, prevent over fishing, and protect endangered species failed to meet any of these objectives (13).

The economic interests that representatives of nation states seek to protect are normally based on the cost-benefit analyses done by mainstream economists, and the results of these analyses almost invariably indicate that the costs of implementing scientifically viable economic solutions are greater than the benefits. This largely explains why scientifically viable economic solutions for global warming did not survive the multi-year process of forging the post Kyoto agreement. All of the existing proposals would allow worldwide emissions of carbon dioxide to increase substantially for ten years or more, and subsequent reductions are intended to stabilize concentrations of this greenhouse gas in the atmosphere between 450 and 550 parts per million (ppm) by 2050.

The problem is that recent scientific research has revealed that if any these solutions are implemented in the final agreement, there is a high probability that global warm-

ing will trigger irreversible large-scale changes in the climate system. The “good news” is that these changes could be avoided by reducing atmospheric concentrations of carbon dioxide from the present 385 ppm to 350 ppm over the next twenty years (14). The “bad news” is that this would require reductions in worldwide emissions of carbon dioxide that are several orders of magnitude greater than those called for in any of the proposals that will be considered during the final phase of forging the terms of the post-Kyoto agreement. Even more alarming, all of these proposals would allow worldwide emissions of carbon dioxide to increase to the point where irreversible large-scale changes in the climate system are likely to occur.

### ***The Stern Review on the Economics of Climate Change***

The most ambitious proposal is the Stern Review on the Economics of Climate Change, developed by internationally known British economist Nicolas Stern and his colleagues (15). This 700 page document is widely viewed as the first systematic attempt by mainstream economists to realistically assess the costs of mitigating the impacts of global warming. But even in the unlikely event that the Stern proposals are implemented in a post-Kyoto agreement, this would not prevent the most disastrous consequences of global warming. This is the case because Stern and his colleagues are practitioners of neoclassical economic theory, and unscientific assumptions in this theory disallow the prospect of implementing scientifically viable economic solutions.

For example, all of the proposals in the Stern Review are predicated on the assumption that “closed” market systems will remain in equilibrium and continue to grow or expand regardless of the disequilibrium that exists in the “external” environment. Based on this assumption, Stern and his colleagues predict that average per capita income and consumption will increase 1.3% per annum until the year 2100, and estimate that the costs of effectively mitigating the impacts of global warming will be 1% per annum of global GNP. Numerous commentators have been impressed by this relatively modest estimate of mitigation costs. But virtually nothing has been said or written about the fact that this estimate is based on the assumption that the average levels of income and consumption for people living in the year 2100 will be 12.3 times greater than they are today.

The inconvenient scientific truth here is that the global market system will not remain in equilibrium and continue to grow and expand in a world where the global climate system is in a state of extreme disequilibrium. In this world, dramatic increases in the intensity and frequency of floods and droughts would cause crop failures and dramatic declines in agricultural production in most regions on the planet. People living in prosperous countries like the United States would experience severe food and water shortages, and those living in poorer countries, particularly in South Africa and central and south Asia, would not have sufficient food and water to sustain their existence.

The melting ice sheets in Antarctica and Greenland would cause sea levels to rise by one to two meters, and densely populated low-lying regions in the Indian subcontinent and elsewhere would become uninhabitable. The disappearance of the mountain glaciers in the Himalayas, Andes and Rocky Mountains would deprive hundreds of millions of people of their primary source of fresh drinking water. In the most severely affected countries, mass migrations of starving and desperate people into neighboring countries would trigger border conflicts that could easily escalate into full scale wars. In one of the regions where this is likely to occur, the full scale war could be between the nuclear armed countries of India and Pakistan (16, 17, 18, 19).

Irreversible large scale changes in the climate system would also disrupt economic activities in every region or territory on the planet. These disruptions would result in large financial losses by business owners and investors, dramatic declines in savings and capital investments, rapid increases in the prices of scarce commodities and foodstuffs, runaway inflation, and massive unemployment. Banking systems and stock markets in underdeveloped and developing countries would collapse, and those in developed countries would suffer catastrophic losses. In contrast with previous financial crises, productivity, profit margins, and returns on investment in stocks, bonds and other financial instruments would continue to decline. And since capital for investment spending would not be available, the global market system would collapse. The obvious conclusion is that if the international community fails to implement a bailout plan for the global climate system, bailout plans for the global market system will only hasten its demise.

## **The “Two Culture” Problem**

In my view, the greatest obstacle to implementing a post-Kyoto agreement that could prevent global warming from triggering irreversible large-scale changes in environmental systems is not the claim that neoclassical economic theory is scientific. It is the problem of “two cultures” famously described by British physicist and novelist C. P. Snow in 1959. Snow was concerned that the single intellectual culture that existed prior to World War II was splitting into two cultures with social scientists on one side of the divide and natural and physical scientists on the other. As it turned out, the two-culture problem was not resolved, the members of these groups became increasingly isolated from each other, and the divide became a yawning chasm.

I argue that failure to resolve the two-culture problem explains why mainstream economists and environmental scientists have virtually no contact with one another and perform completely different roles and functions during every stage in the process of developing economic solutions for environmental problems. This largely explains why the language used by one group is often incomprehensible to those in the other and why other large cultural differences exist. These differences include alternate worldviews, disparate values, and diverse and incompatible rules for gathering evidence and making predictions based on this evidence.

The most expedient way to resolve this two-culture problem is also the most efficient way to develop scientifically viable economic solutions for environmental problems. The solution is to create institutional frameworks and processes that require mainstream economists and environmental scientists to work closely together during every stage in the process of developing these solutions. But this vital enterprise will not be successful unless the scientists and economists who participate in this process are willing to adopt a reconciliatory posture and engage in an open and honest debate about knowledge claims on both sides of the two culture divide.

The economists might not appreciate being told that the economic theory they have used throughout the past century is predicated on unscientific assumptions. And the scientists may not appreciate being told that the benefits of protecting environmental resources must be evaluated in terms of the economic losses that could be suffered by people who depend on these resources for their liveli-

hood. But this dialogue could be both highly beneficial and productive if the members of both cultures realize that the objective is not to win an intellectual debate or defeat an intellectual foe. It is to achieve the level of mutual cooperation and understanding required to realize a rare opportunity. The opportunity is to protect the lives of the 6.9 billion members of the extended human family and the future existence of subsequent generations of this family by developing and implementing scientifically viable solutions for environmental problems. In this grand enterprise, the public good is human ecology writ-large and this good would be viewed as dependent on and nested within the global environment.

During his presidential campaign, Barack Obama repeatedly said that his administration would do all that is required to effectively deal with the problem of global warming. If now President Obama intends to keep this promise, I believe that there are three initiatives that should be at the top of his political and legislative agenda. The first is to create a federally sponsored commission in which mainstream economists and environmental scientists will work closely together to develop scientifically viable economic policies and programs that can reduce worldwide emissions of carbon dioxide to levels where large scale irreversible changes in environmental systems the will not occur. The second is to develop a proposal for implementing these policies and programs in a post-Kyoto agreement that privileges the well being of all of humanity over the narrowly defined and short sighted economic interests of the United States and other developed countries. And the third is to use the diplomatic and other resources required to ensure that this proposal is implemented during the final phase of forging the terms of this agreement. If this initiative is successful, Barack Obama will be remembered not merely as a great American president, but also as one of the most humane and enlightened political leaders in the annals of human history.

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### **Conflict of interest**

*None.*

### **References**

1. Hard times about the bailout. *The New York Times*. 2008 Sept 20; Editorial.

2. Mirowski P. *Against mechanism: protecting economics from science*. Lanham, Maryland: Rowman & Littlefield; 1988.
3. Nadeau R. *The wealth of nature: how mainstream economics failed the environment*. New York: Columbia University Press; 2003.
4. Nadeau R. *The environmental endgame: mainstream economics, ecological disaster, and the human survival*. New Brunswick: Rutgers University Press; 2006.
5. Ingrao B, Israel G, tr, MacGilvray I. *The invisible hand: economic equilibrium in the history of science*. Cambridge, Mass: MIT Press; 1990.
6. Hanley N, Shroegren JE., White B. *Environmental economics in theory and practice*. New York: Oxford University Press; 1997. p. 358.
7. Hanneman WM. Valuing the environment through contingent value. *Journal of Economic Perspectives*. 1994 fall; 8(4): 19.
8. Sagoff M. Some problems with environmental economics. *Environmental Ethics*. 1988 spring; 10: 55.
9. Mitchell RC, Carson RT. Valuing drinking water risk reduction using the contingent valuation methods: a methodological study of risks from THM.
10. Tolley G, et al. Establishing and valuing the effects of improved visibility in eastern United States. paper prepared for the Environmental Protection Agency, Washington, D.C., 1986.
11. Bowker J, Stoll JR. Use of dichotomous choice non-market methods to value the whopping crane resource. *American Journal of Agricultural Economy*. 1987 May; 23(5): 372-381.
12. Boyle KJ, Bishop RC. Valuing wildlife in benefit-cost analyses: a case study involving endangered species. *Water Resources Research*. 1987 May; 23(5): 943-950.
13. Speth, JR. *Red sky at morning: America and the crisis in the global environment*. New Haven: Yale University Press; 2004. p. 77-98.
14. Hansen J, Sato M, Kharecha P, Beerling D, Masson-Delmotte V, Pagani M, Raymo M, Royer DL, Zachos J. Target Atmospheric CO<sub>2</sub>: where should humanity aim. *Atmospheric and Oceanic Physics*. 2008; 2: 217-231.
15. Stern N. The stern review on the economics of climate change. Available from: [http://www.hm-treasury.gov.uk/sternreview\\_index.htm](http://www.hm-treasury.gov.uk/sternreview_index.htm).
16. Parmesan C. Ecological and evolutionary response to recent climate change. *Annual Review of Ecology and Evolution of Systems*. 2006; 37: 637-639.
17. Hansen J, et al. Dangerous human-made interference with climate: A GISS model study. *Atmospheric Chemistry and Physics Discussion*. 2007; 7: 2287-2312.
18. Marshall J, Solomon S, et al., editors. *Intergovernmental panel on climate change. Climate change 2007*. New York: Cambridge University Press; 2007.
19. Final report of synthesis and assessment product, 4.1, 4.2, 2.3, 1.2. U.S. Climate Change Science Program, Avail from: [www.usgcrp.gov](http://www.usgcrp.gov).