SURVEY

Political Economy of Climate Change, Ecological Destruction and Uneven Development

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ABSTRACT

The purpose of this paper is to analyze climate change and ecological destruction through the prism of the core general principles of political economy. The paper starts with the principle of historical specificity, and the various waves of climate change through successive cooler and warmer periods on planet Earth, including the most recent climate change escalation through the open circuit associated with the treadmill of production. Then we scrutinize the principle of contradiction associated with the disembedded economy, social costs, entropy and destructive creation. The principle of uneven development is then explored through core-periphery dynamics, ecologically unequal exchange, metabolic rift and asymmetric global (in)justice. The principles of circular and cumulative causation (CCC) and uncertainty are then related to climate change dynamics through non-linear transformations, complex interaction of dominant variables, and threshold effects. Climate change and ecological destruction are impacting on most areas, especially the periphery, earlier and more intensely than previously thought likely. A political economy approach to climate change is able to enrich the analysis of ecological economics and put many critical themes in a broad context.

Keywords: political economy; principles; climate change; ecological destruction; uneven development;

1. Introduction

For decades global warming hypotheses have been a contested terrain as advocates sparred with critics, resulting in controversy and analysis, but no firm resolution either way at the level of public debate. All this has suddenly changed in the light of the ‘global warming’ thesis gaining the upper hand. The influence of Al Gore’s (2006) film *An Inconvenient Truth,* publication of the *IPCC Report* (2007a,b,c,d), the *Stern Review* (2007), the *UNHD Report* (2007), and the *Garnaut Report* (2008), plus several interest groups have meshed with the election of more moderate governments in several continents to change the public view of these matters. ‘Climate change’, as it is now called, has become an accepted institution, even by most of those who previously argued against ‘global warming’. Even so, there are still pockets of vehement opposition, including, for instance, the brilliantly produced but seriously problematic *The Great Global Warming Swindle* (GGWS 2007) documentary, which should be required viewing for all ecological economists, at least as prime entertainment with considerable shock value.

Despite several debates and criticisms of these reports, by-and-large their impressive scientific and policy pronouncements have been widely acclaimed. It has now become the norm to take a multi-disciplinary, even perhaps a transdisciplinary, approach to climate change. Marginal analysis is eschewed since the sort of changes we are viewing are quite major, and cost-benefit analysis is underplayed due to the deep uncertainties involved in every aspect of the problem. These uncertainties do not challenge the general idea of climate change, but indicate that threshold effects such as major ice-sheets melting or shifting in the Arctic region, Greenland and the Western Antarctic are likely happening sooner than later, while coral bleaching is likely already upon us. Much of the methodology of these reports is similar to the concerns of ecological economists and political economists. However, it is likely that these reports underplay critical concepts and processes, including changes in institutions and systems (rather than simply technology and 'policy issues'); the social costs embedded in the treadmill of production (rather than resolution through market valuation policies); the structural connection between the costs imposed on the periphery and benefits directed to the core nations; ongoing entropic degradation of energy-matter (rather than sustainable production and development); and the likely earlier onset of destructive tipping points.

These critical concepts of institutions, social costs, production treadmill, core-periphery relations, and cumulative entropic degradation are those of modern political economy. Recently many trends in (heterodox) political economy have been undergoing a degree of convergence and integration which has expanded the range of its research programs (Lee 2009), and some general principles are emerging (O'Hara 2007a,b). Political economy has begun to branch out of its already rather broad 'disciplinary space' into transdisciplinary areas of concern such as AIDS, terrorism, crime and injustice (O'Hara 2009). However, this journal has so-far not published material linking political economy principles explicitly to climate change, though it has published numerous political economy papers on the environment (e.g., Burkett 2004, Forstater 2004, Schor 2005, Hornborg 2006, Brennan 2008, Berger 2008a). Hence this paper, which 'applies' political economy principles to the interplay between climate change and ecological destruction. Special emphasis is given to work within and between the fields of institutional, Marxian, evolutionary, sociological and post-Keynesian political economy.

The paper starts with the principle of historical specificity, which states that history is an important starting point in a political economy perspective. Here climate change is embedded into the historical process, including the evolutionary transformation of capitalism. Then the paper examines the principle of contradiction, including the disembedded economy, social costs, entropy and the accumulation of capital that link to the destruction of environmental resources and climate patterns. The principle of uneven development then reveals serious conflict between core and periphery, and why policy may fail to change the world for the better. The principle of circular and cumulative causation is used to identify the major causes of greenhouse gas emissions and their impact on climate. This leads to the principle of uncertainty, as several deep ambiguities necessitate an evolutionary and non-linear analysis of threshold effects and cumulative impacts.[1]

2. Principle of Historical Specificity

One of the defining characteristics of political economy is its historical foundation, since it relies on history to assist in comprehending evolutionary processes. Grand political economists such as Karl Marx, Thorstein Veblen, John Maynard Keynes and Joseph Schumpeter (and their followers) embedded history in their political economy approaches. Numerous more recent scholars, such as Michael Howard and John King (1985) and Geoffrey Hodgson (2004) specifically cite the principle of historical specificity. According to this principle, history provides a corpus of knowledge concerning stages and phases of evolution, life cycles, changing habits and technologies, and path dependent patterns. Without history, political economy would be a mere formality, lacking in operational, social and organisational content. This is especially the case with climate change, as it is necessary to situate it within the framework of past phases of change and metamorphosis.

It helps to comprehend in broad terms the waves and patterns of climatic change through the millennia. Several waves and changing patterns of climate have been apparent through the life-history of the world (Moberg et al 2005:616). There were 100-140m-year long waves during the Phanerozic eon (1-500m years BP; 'before the present'), and 70,000-115,000 year long waves during the Pleistocene era (15,000-500,000 years BP). The two eras were characterised by recurring hot and cold waves, usually culminating in successive glacial or ice ages during the cold periods, followed by periods of much warmer weather. Less regular long patterns have been operating during the Holocene period when human beings *settled most of the areas of Earth* (0-12,000 years BP). For instance, just before and during the early years of the Holocene "human era" there was a period of sudden and very deep cooling and glaciation between 12,700 and 11,400 BP, then rapid change from glacial to warm conditions more suitable for human habitation between 11,000 and 10,000 BP (2-3 C° warmer than before). This was followed by a somewhat cooler period from 9,300 to 8,000 BP (0.5 °cooler than normal), and then a warmer period from 8,000 to 6,500 BP (between 0.0 °C and 0.3 °C warmer than normal). The next 2,000 years from 6,500 to 4,250 BP was fairly stable around the norm.

In a long perspective, the whole period from 4,250 to 150 BP looks decidedly like a transition to colder temperatures until industrialisation commenced in Britain. When examined more narrowly, 0 to 800AD exhibited a stable cold tendency (0.6 to 0.2°C cooler than the norm), followed by a medieval warm*er* period from 975 to 1425 AD (0 to 0.2 °C *below* norm), a little ice-age (especially in Europe) from 1440 to 1710AD (0.4 to 0.9 °C below norm), and then since 1850 a progressively warmer era (0.0 to 0.5 °C above norm).

None of these waves or periods before 1850 were *anthropogenic*; i.e., caused specifically by humans (or other animals). They were caused by things such as changes in the tilting of the Earth's axis, volcanic forcing, or

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[1] An additional section on 'policy' has been omitted due to space requirements, but a separate article on this is available (O'Hara 2010).

solar irradiance. The more recent trends concerning climate are the first to be precipitated by human beings or 'non-natural' forces. The current period of expansion of greenhouse gasses commenced at a low base during the industrial revolution from the mid-1850s, but did not noticeably increase until the 1950s and 1960s, thereafter showing upward warming from the 1970s through to the 2000s (UNDP 2007:32; IPCC 2007a:6,48,49). In the early 1900s sea levels noticeably rose. The warming trend became especially noticeable in the mid-1900s, but did not become a serious threat until the oceans became a less efficient sink in the 1970s onwards. Since then the signs have been there in abundance for serious CO_2 emissions, rising temperatures, further expansion in sea levels, modified precipitation and wind patterns, greater extreme events, plus the melting of ice-sheets.

The reason for the rising greenhouse gas levels is the rapid expansion of a new economic system that commenced its industrial phase in the mid-1800s, especially in Europe and North America. This system of "industrial capitalism" was based around different class processes of capitalists and workers, coal-and-later-oil-fired engines, production of steel, technological expansions and productivity increases. It also gradually began to penetrate the market for consumer goods, and the so-called 'first phase of globalisation' ('concerted imperialism') began in earnest in the 1880s-1910s as it was 'exported' to many further areas of the world. Capitalism is a class system based on deep capital structures, with often complex input-output linkages and changing production processes, products, corporate systems, markets, and raw materials.[2]

Capitalism in the contemporary world is a mixed system of private enterprise and government, along with non-capitalist institutions such as the family and community. The system revolves around business processes, such as innovation, markets and finance. Marx's (1885) circuit of money capital (CMC), when situated as an *open system*[3] linked to social and environmental processes, is useful to understanding its operational dynamics.[4] Initially see Figure 1 below for this circuit:

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[2] According to Resnick and Wolff (2002), capitalism existed in Central and Eastern Europe as state capitalism during the 1920s-1980s as the bureaucrats expropriated the surplus normally distributed to private owners or managers. Other neo-Marxist views are that the Soviet Union and its allies were variously "state socialism" or the "Soviet" mode of production.

[3] The notion of open systems *in political economy* goes back to many scholars, including Marx and Veblen. In more modern work, the scholarship of K. William Kapp (see 1976) is especially important. Kapp situated open systems in Marxist and institutionalist thought (p. 91) and deepened its ecological and social significance.

[4] The reason for extending the open nature of the circuit of money capital relates to the argument of Herman E. Daly (1985:280) that "Marx's models of simple and extended reproduction are basically isolated circular flows. Contacts with the environment are played down because resources are held to be free gifts of nature, not a source of value independent of labor." While this may be true, 'the circuit;' is not the models of simple and extended reproduction, and Marx does link the circuit to both labor and nature contributing to use-values, and the processes of metabolic rift. Nonetheless, making the circuit (or treadmill) a deeply open system embeds ecology and society into the capitalist process more specifically.

This (open) circuit as a whole has the logic of the "treadmill of production", which many sociological political economists have been using to describe the ongoing dynamics of capitalism. John Bellamy Foster (2009:48) defines the treadmill of production as "an unstoppable, accelerating treadmill that constantly increases the scale of the throughput of energy and raw materials as part of its quest for profit and accumulation, thereby pressing on the earth's absorptive capacity." Within this open and circular treadmill, familial reproduction and the financial system is added to the usual flow of processes, while the circuit is set within a wider system including solar energy, the ecological environment, the systems of geology, oceans and spatiality, as well as the social and political environment. In this context, the family (plus the community and state) can contribute negatively or positively to the reproduction of labor power, while it can also contribute through enhancing market exchange as non-market activities become marketised. Money (M) is then used to buy commodities (C), both labor power (LP) and means of production (MOP), including machines, buildings and factories plus non-renewable resources such as oil, gas and coal. The system of production then comes into play with the transformation of matter-energy from low to high entropic processes (Georgescu-Roegen 1971). Out of this production process emerges commodities (including services), with a value equal to the inputs (C), plus usually a surplus product (c) over costs of production. Then the Keynesian problem emerges concerning selling goods and services for money, including a surplus value (m) (profit, interest and rent). Here consumption demand becomes a core concern. After that it is crucial that the capitalist instinct be sufficiently developed to re-invest the sales money, along with credit, bond money or the original selling of shares through the financial system. The faster this circuit turns over the greater is the surplus value that can be used for investment, dividends and managerial salaries, or other purposes. But as this happens the resources become increasingly unavailable in an entropic sense.

This circular treadmill of production[5] is thus dependent upon expanding the sphere of markets in order to transform non-market relations into new means for profit. Cheap ecological resources are required, below their renewable cost, to enhance profit; as is the turning of non-market familial production into capitalist production; expanding the world in search for new markets to commodify; and generating new needs and wants for consumers, along with the credit system to expand profit. Turning things into commodities is thus the way to generate new profits, especially if their cost of production is low due to cheap methods of exploiting resources and other inputs. The circuit as a whole also requires government to provide a system of laws and property rights to protect systems of profit and accumulation; plus fiscal and monetary policy to ensure renewal of the circuit through time. It is assisted by consumers in the habit of buying and selling as means of reproducing

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[5] See the journal, *Organization and Environment* (in recent years, especially Volume 17, Number 3, and Volume 18, Number 1) for several papers on the treadmill of production. For instance, Foster (2005:13) argues that Allan Schnaiberg's treadmill of production model is perhaps related to Marx's political economy in a similar fashion to Veblenian political economy, since "it could be used to convey critical ideas to those who otherwise would be resistant." Foster seems to prefer the term "treadmill of accumulation" "in terms of Marx's general formula for capital—M-C-M'" (p.14), which is identical to the circuit of money capital used in this paper, except that here the model is linked to broader influences.

everyday life, expanding credit usage and engaging in Veblenian conspicuous consumption and emulation to enhance the circuit. Preferences have endogenously eschewed sustainability in the pursuit of profit and consumption, affected by social and business norms (Sabine O'Hara 2001, 2002), while "the earth remains in large part a "free gift to capital"" (Foster 2002:11) as the circular treadmill accumulates and profits from the motion.

Extending these processes even more to the ecological and social system implies the existence of an integrated (open and partly uni-directional) circuit of human-ecological greenhouse gas emissions (GHGE) and climate change, as shown below in Figure 2:

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This integrated (open) circuit shows the linkages between the circular treadmill of money capital (CMC), land use clearing (LUC) plus emissions (EM) of carbon dioxide (77% of total Co_2-e emissions in 2000), methane (CH_4; 14%), nitrous oxide (N_2O; 8%), plus hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6s) (1.7%) (Stern 2007:198). There are thus significant emissions of carbon dioxide equivalents (CO_2-e) or GHGs, including the process of radiative forcing (RadForc) after a lag, and associated climate sensitivity parameters (λ), producing changes in temperatures, rising sea levels and changes in current, wind and rain patterns. These can feedback through to other aspects of the climate system (with lags), along with other (feedback) impacts on various systems in the physical, biological and human domains (with further lags).

Some common scenarios linking CO_2-e flows (GtC yr) with CO_2-e stocks (ppm) through time have been formulated (see Plattner et al 2008:2736). The IPCC report presented scenarios rather than suggesting appropriate targets (but it did specify (IPCC 2007c:173) "stringent scenarios" of 445-490ppm Co_2-e likely leading to *more* than a 2°C rise in temperature since pre-industrial times). For preventing major threshold problems from emerging, the Stern Report (2007:xvi) presented optimistic "required" stabilization stocks of between 350–450ppm Co_2 (≈450–550ppm Co_2-e), compared with the UNHD Report (2008:7) which argued for 350ppm Co_2 levels (≈450ppm Co_2-e levels).[6] 2005 CO_2 emission flows are about 28 G_tC (385ppm stocks), and they need to decline to between 3.1 and 6.7 G_tC (uncertainty ranges) to achieve the more optimistic Stern CO_2 stabilisation level of 450ppm CO_2 by 2050; and further to between 1.4 and 3.8 G_tC by 2100. But for this

[6] There is confusion in the literature about CO_2 and CO_2-e stocks. As an over-simplified rule, one can use CO_2 rather than CO_2-e contributions to radiative forcing, since the difference between CO_2 and CO_2-e is *negative* forcing components such as aerosols and surface albedo (IPCC 2007a:4). Specifically, total CO_2 (93%) plus natural solar irradiance (7%) contributions equal total net anthropogenic radiative forcing. However, the level of scientific understanding of CO_2 is much greater than most other radiative forcing elements, and they have differing impacts through time. Richardson et al (2009:18) state about CO_2 and CO_2–e that: "Today, the Co_2 concentration is around 385ppm, and is rising by 2ppm per year, The 2007 concentration of all greenhouse gasses, [CO_2-e]… was 463ppm. … Adjusting this concentration for the cooling effects of aerosols yields a CO_2-equivalent concentration of 396ppm." (As a broad approximation one could assume that 350ppm CO_2≈450ppm Co_2-e, ignoring the negative elements associated with aerosols etc. and uncertainty levels.)

scenario to hold, reducing emissions to low levels is necessary almost immediately, since there are lags between reduced emissions and eventual "stabilisation" of CO_2 stocks. There is, however, a growing movement for a CO_2 eventual "stabilisation" level of 300ppm (≈400ppm CO_2-e) (see Hansen et al 2008), which will likely require substantial social and political change to transcend the circular treadmill of accumulation.

3. Principle of Contradiction

There are many *interrelated* contradictions associated with the open circuit of money capital, which have been variously documented by the grand political economists of the past, including Marx, Veblen, Keynes and Schumpeter and their followers. These contradictions include, for instance, that between capital and labor, finance and industry, monopoly and competition, men and women, and so on (see O'Hara 2001). Some that specifically relate to climate change are the contradictions between ecological resources and profit, and the related one between core and periphery, which are examined in this and the next section.

The principal general contradiction is that of the disembedded economy (Brennan 2008); namely, Karl Polanyi's (1944) idea that capitalism undergoes the process of destructive creation, variously destroying socio-ecological resources in the very process of creating market value, with many of these destructions not being included in the market valuation of goods and services. These things which orthodox economics calls externalities are actually endogenously necessary "social costs" for business enterprise to generate a sustainable profit. The disembedded economy is based on the notion that there are various "fictitious commodities" involved in the treadmill which tend to be under-reproduced if markets are left to their own devices. These include labor power, money and the environment, all of which require for their proper maintenance many more resources than the free market is likely to provide. Extra resources need to be generated for these spheres, even for the long-term functioning of capitalism, and even more resources for systems of lower community and entropic degradation. Hence we see the operation of the double movement, that capitalism variously moves between complex systems of insufficiently providing such resources (on the one hand), while the state and community respond in certain historical junctures with many more resources for their reproduction (on the other hand). Capitalism as a whole thus moves through cycles and waves of insufficiently and over-sufficiently providing these resources, which is a prime dynamic of the system generating instability and motion.

Through such motion, the market system evolves through varying types of transactions such as exchange, redistribution and reciprocity to provide for more integrative structures of human labor power, central banks/lender of last resort facilities and environmental protection requirements and institutions. The three quasi-commodities are not separate but are necessarily seen as part of the same general process of capitalism insufficiently providing for the system-requirements of complex socioeconomic processes, and perpetually being limited by the dynamics of individual capitals (which limit such resources), capitalism as a whole (which also limit them by community standards), and community requirements (which exceed the limits of capital). Indeed, the core contradiction of capitalism, according to Polanyi, is simply this, that private property and profit through market exchange is dependent upon continual commodification of labor power, money and natural resources to extend accumulation and profit.

Key specific insights into aspects of this disembedded economy can be gained from the work of political economists such as Karl William Kapp, Nicholas Georgescu-Roegen, James O'Connor and John Bellamy Foster. These four scholars, in particular, develop 'open-systems' and teach us that social and environmental costs of growth and profit require us to go beyond market valuation in determining solutions to resource preservation and utilisation.[7]

Kapp's (1978: 31-37, 42-46) theory of social costs drew some inspiration from Polanyi, since he saw Polanyi's work as "an illustration of what can be done in rewriting history if … social costs are kept in view" (p. 45). He also drew heavily from Marx, especially in relation to "Capitalist production … sapping the original sources of all wealth—the soil and the labourer" (p. 36), and Veblen (along with "some his followers") who "analysed a wide variety of social costs which arise primarily in connection with technical progress, depressions and monopolistic practices" (p. 44). In his magnum opus, *The Social Costs of Business Enterprise* (various editions, e.g., 1978), Kapp saw the institution of business enterprise (whether privately or publically owned) to be based on the permanent revolution of technology and accumulation in the interests of the corporation. Such a revolution generates non-linear and cumulative changes that variously abstract from numerous socio-ecological costs. Kapp is especially concerned with the category of renewable resources vis-à-vis ecological balance between the land and its vegetative "cover" (along with waterways and fish stocks). With non-renewable resources such as petroleum, coal, natural gas, and other minerals his concern is with the finite stock as the business system expands cumulatively (and with volatility) through historical time. With the human factors in production he is concerned with the inability of the business system to suitably reproduce the conditions of fullness of life in the working population; along with duplication, obsolescence, and misallocated resources as forms of waste. These conceptually linked but heterogeneous, quantitative and qualitative social costs, are said to impair the socio-ecological environment, in a cumulative and irreversible manner.

Kapp's core thesis is that as renewable resources are increasingly exploited they are subject to a "critical zone" of cumulative "irreversible depletion and exhaustion", likely long before the supply of such resources reach zero. This is especially the case with soil, forests, wildlife such as fish and many other natural assets. Non-renewable resources are also subject to a cumulative process of exploitation which competitive forces tend to exhaust so that they can move onto other more remunerative sources. Competition forces lead to "unnecessary

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[7] Kapp's work developed in the interface between institutional and ecological economics (Kapp 1974) (see also Elsner et al 2006, Berger 2008b), while the most important reference for Georgescu-Roegen on energy is Georgescu-Roegen (1975). Kenneth Boulding's (1945, 1949-50) analysis is also important, since for him the objective of economics is to stimulate the continuation of durable structures that provide services, and not consumption ("destruction") since this wastes resources. Boulding (1981) links the entropy process to "the law of diminishing potential" as resources are consumed rather than maintained. (See also Boulding 1966.)

duplication of capital outlays" and "premature depletion" of many reserves to the dis-benefit of future generations. Similar types of processes are said to impact on labor in terms of conditions of work, wages and unemployment. These cumulative socio-ecological processes are exacerbated by other competitive conditions such as cyclical trends, excess capacity, obsolescence and misallocation of resources inherent in the business system. He goes as far as to say that "the organising principles of economic systems guided by exchange values are incompatible with the requirements of ecological systems and the satisfaction of basic human needs" (Kapp 1976: 95), and posits the need for a theory of social valuation in a modern system of "political economy" (Kapp 1978: ch 15) that includes the social control of business, a recognition of the heterogeneous nature of these costs, and the "broadening of the scope of economic investigation" (p. 284) especially into quality of life issues and processes.

Georgescu-Roegen, with a "degree from Universitas Schumpeteriana" (the same class as Nicholas Kaldor and Oscar Lange at Harvard), developed a system of "dialectics" and "process" (Georgescu-Roegen 2000: 221, 223). He started his ecological political economy from two propositions, one gained from Marx, that "the economic process is not an isolated system" (1966:101), and the other from Marx and Veblen (and others), concerning more interest in "distributive relations than in the efficient allocation of means" (p. 106). Embedding political economy in an open system concerned with distribution, he was able to situate the industrial system as having a relatively short life cycle of perhaps only a few hundred years. In his works, there is a core contradiction of the industrial treadmill involving thermodynamic systems. The first law states that energy and matter can be neither created nor destroyed, but they can change their form from (for instance) sunlight to terrestrial forms to minerals to waste. The second law associated with this contradiction is that in a closed system the energy-matter being worked on tends towards greater levels of unavailability or entropy. The industrial system, moreover, draws much of its free energy-matter from existing forms such as minerals, oil and established forests and fields, and comparatively little from the ever-present source of energy from the sun (in an open system). Industrialism thus uses free energy to produce structured products and waste which through successive rounds of usage and recycling become increasing unavailable for use as 'bounded' forms expand. Such a system, therefore, must necessarily access free energy directly from the sun or face a very limited lifetime as the resources become used up and/or generate extreme climate events that destroy human and ecological potentiality.

Traditional economics ignores this purely physical limit to production, consumption and distribution, since it assumes that while resources are relatively scarce, there are always substitutes and trade offs that ensure sustainability in the long-run. Georgescu-Roegen teaches us that an economic system based on accumulation and growth cannot continue to be reproduced in the long-run because resources will be used up, producing masses of bounded waste and hence unavailable energy-matter. The entropy from produced products is lower than that of the inputs into production only because of waste, and when the products are consumed the waste accumulates further. Thus a purely circular process is impossible because the entropy is a leakage from the system, which gathers momentum along with growth and consumption. Free energy is limited by the use of established terrestrial stocks of minerals, soil, plants and animals which become bounded as human population and industry expand, generating a depletion of low entropy. The core contradiction becomes one of the present system generating industrial and consumption advances to the exclusion of future generations of human beings and other species (Georgescu-Roegen 1973:57-58). During the 1980s and 1990s, Georgescu-Roegen grew "tired of trying to convince the champions of 'sustainable development' that this plank is even more foolhardy than 'steady state'; that even a steady state needs a constant flow of resources that are continuously and irrevocably degraded into waste as the entropy law requires" (2000: 224).[8]

These contradictions of the disembedded economy, social costs and entropy are closely linked to certain neo-Marxian ecological views of political economy, especially the work of James O'Connor, John Bellamy Foster and Paul Burkett. O'Connor's analysis of the second contradiction of capitalism was partly inspired by Polanyi's analysis, while Foster and Burkett's work is broadly consistent with that of Polanyi, Kapp and Georgescu-Roegen. O'Connor argued that the first contradiction of capitalism is associated the capital-labor conflict and the tendency to overproduction and underconsumption crises. His second contradiction is associated with the conflicting forces of accumulation and production conditions; the latter including urban space and infrastructure, labor power, and the natural environment.[9] In this context, climate change is specifically linked to the conflict between accumulation and ecological resources (O'Connor 1991, 1994). The key point O'Connor makes is that the "social costs" of these conditions of production will increase crisis tendencies for capital as they impinge on businesses either directly through greater private costs, or through the efforts of state intervention and new social movements such as the environmentalists, community activists, and feminists.

Many scholars have made the point that the relationship between accumulation and environmental destruction and hence climate change is closely linked to the first contradiction of capitalism (as is labor power and space). They argue that it is perhaps more likely that capital will continue to accumulate in large measure "free" of these social costs as the treadmill of production continues in a business-as-usual manner since climate change (and ecological) governance is likely to fail to reach global accord in an effective manner. Capital is also benefitting from the destruction of natural resources through marketization of ecological problems and waste (see Spence 2000, Foster 1992, 2009, Burkett 2006). In this perspective, there is a first-order relationship between the accumulation of capital in the treadmill, plus the anomalous reproduction of labor power, public space, and natural environment. In addition, according to Burkett (2006), more emphasise should be given to organisational and systemic 'qualitative forms' of eco-human reproduction, 'human beings co-evolving with

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[8] Georgescu-Roegen (1973: 53, 59) further argued that "the true economic output of the economic process is not a material flow of waste, but an immaterial flux: the enjoyment of life", and that the "discovery" of being able "to transform solar radiation into motor power directly" will "represent the greatest possible breakthrough for [the human] entropic problem."

[9] This critical analysis of the "second contradiction" is a brief review of some of the arguments in the literature, since space considerations limit a detailed investigation. For a somewhat fuller coverage of the material, see the references mentioned in the text of this paper plus the cyberbook published by the Centre for Political Ecology (CPE 2000).

other species and the entire biosphere', 'alternative forms of waste management and prevention', plus the 'environmental requirements of human development', rather than internalising costs into the current system of market valuation, profit and accumulation.

But how have accumulation contradictions affected the natural environment per se? The real foundations for the contradictory link between environmental destruction, climate change and the dynamics of business are certain opportunity costs ("unpaid costs" Foster 2009:207) associated with building human resources, such as durable fixed business capital, physical infrastructure and commodity capitals within the open circuit. These opportunity costs include the continual over-use of non-renewable minerals and resources; the emergence of various critical zones of destruction of renewable resources; and the encroachment of human populations and industry that reduce species numbers and genetic quality as well as increasing the stock of greenhouse gasses.

In this context, over the period 1970 to 2005, as global real GDP expanded from $13,764b to $44,925b (226%) and global population from 3.7b to 6.5b (75%), the global flow of CO^2 emissions increased from 14Gt to 28 Gt of CO^2 (100%) while stocks rose from 322ppm to 379ppm (15%). As this occurred, the global stock of species, *proxied* by the Living Planet Index (LPI)[10], declined from 100 to 72 (28%), and the global ecological footprint[11] increased from 0.6 to 1.3 (117%). Over the same 35 year period, global ocean heat content rose from 1.7 to 6.0 (10^{22}J), global land surface temperature expanded from 13.65 to 14.47 °C, and global mean sea levels rose from -22 to 70mm (relative to the 1961-90 mean). On business-as-usual assessments, by 2100, atmospheric greenhouse stocks could go as high as 700-900ppm, global surface warming (since 2000) could escalate by 4-5 °C (with a range of between 2-7 °C), likely resulting in over 50% of the species becoming extinct, with major threshold effects such as Arctic sea ice melting, Greenland ice sheet declining over the landmass, the Western Antarctic ice sheet separating from the bedrock and the Atlantic thermohaline circulation causing major climate change especially in the North Atlantic regions.[12]

Most of the climate change reports emphasise adaptation and mitigation policies to respond to climate change problems, including regulations, taxes, permits, agreements, subsidies, incentives, technological changes, informational instruments, and pricing (IPCC 2007c:ch 13; Stern 2007: Parts IV, V, VI; UNDP 2007:

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[10] The Living Planet Index is based on 3600 populations of more than 1300 vertebrate species around the world, subdivided into 695 terrestrial species, 274 marine species and 344 freshwater species. For the LPI, the Earth's surface is divided into 14 terrestrial habit types and 8 biogeographic habitat covers. Data are from a variety of sources, including scientific journals, NGO literature and the Internet. Plants and invertebrates were excluded due to lack of data. (WWF et al 2008.)

[11] The ecological footprint "measures humanity's demand on the biosphere in terms of the area of biologically productive land and sea required to provide the resources we use and to absorb our waste". "A country's footprint is the sum of all the cropland, grazing land, forest and fishing grounds required to produce the food, fibre and timber it consumes, to absorb the wastes emitted when it uses energy, and to provide space for its infrastructure." (WWF et al 2008:14).

[12] These statistics are based on the UNDP (2007:ch 1), IPCC (2007a:ch 10; 2007b:ch 4) and Stern (2007:ch 7) reports.

chs 3,4). These changes are unlikely to see sufficient systemic changes to reduce the intensity of these contradictions, and many now see an eventual required stabilisation level of 300ppm for Co_2 (see Hansen 2008-09), especially (but not just) in view of the evidence of the past few years that more extreme events are happening earlier than expected from the IPCC, Stern and UNDP reports (Richardson et al 2009). Political economy teaches us that on current trends (even before the recent upscale assessments) a more embedded socio-ecological future looks unlikely unless we are able to replace the contradictions of the circular treadmill of production with a system with much lower social costs and entropic degradation.

4. Principle of Uneven Development

Political economy historically has embedded the economy in real world processes, including the asymmetrical influence of geography, industrial development and culture. Empirical evidence has revealed various uneven processes operating on a global scale, including the tendency for some nations and areas to develop hegemonic trends while other areas have much lower levels of political-economic power. While some degree of convergence may emerge from time to time, this uneven distribution of power in the world economy has always been a core element of political economy. This has been embedded in the work, for instance, of Stephen Hymer, Paul M. Sweezy, Samir Amin, Andre Gunder Frank, Immanual Wallerstein, Amitava Dutt, and many others. Most of this research examines the relationship between core, semi-periphery and periphery within the world-system, including applications, for instance, to climate change and ecological destruction. These ecological and climate debates (linked to broader questions of metabolic rift) have been ongoing in such journals as *Organization and Environment,* the *Journal of World-Systems Research,* the *International Journal of Comparative Sociology*, *Human Ecology Review* and *Monthly Review*.

A core fact is that the circular treadmill of production generates unequal global, regional, national and local power relations and material-labor flows through historical time. Some areas are able to develop articulated linkages through production networks and commodity chains, manifesting in high technology processes and expanded market production. Power and accumulation change through historical time as, for instance, 'Dutch' hegemony evolved eventually to British hegemony and later to US hegemony and beyond. At present advanced capitalist economies are undergoing the process of maturation while East Asian economies, particularly China, have been undergoing a remarkable industrial transformation. While this has been going on many parts of Sub-Saharan Africa, Latin America, the Middle East and South Asia have been unable to significantly advance the relative living standards of their populations (with some exceptions in the semi-periphery).

These forms of uneven development impact on climate change and human development. Generally, over the long-term, most areas of the periphery are stalling relatively speaking in the treadmill of production while contributing less to climate change than those of the core. There are differentials according to per capita and total emissions of greenhouse gasses (UNDP 2008). In terms of absolute and per capita emissions, the US leads the pack, along with other Western capitalist areas (such as the European Union). China has joined the major polluters in *absolute* terms, since its level of capitalist development has been expanding rapidly, but its level of per capita emissions is extremely low (although rising rapidly). Sub-Saharan Africa and most other peripheral areas have contributed a low absolute and per capita level of emissions, along with several semi-peripheral areas. Generally speaking, accumulation and growth are positively linked with emissions and greenhouse gasses, but the social and environmental costs of climate change are being felt disproportionately in the periphery.

Some empirical dimensions of this uneven development and asymmetric climate change impacts are mentioned in the IPCC (2007b), *Stern Review* (2007: ch 1) and the UNDP (2007: ch 2) reports. The UNDP report (especially) emphasises that the 'less developed nations' will be relatively less able to cope with problems of rising sea levels and major climate catastrophes. They are said to lack the resources that the advanced capitalist nations have to respond to such problems. They are also more severely subject to climate catastrophes and excesses than the advanced nations. The severest forms of climate change are emerging, and will continue to emerge at a faster rate in and around the tropics and sub-tropics (along with high latitudes). Less developed nations are thus impacted through climate crises in a manner inversely related to their relative contribution to greenhouse gas accumulation (compared with industrial nations). This uneven impact has been ongoing for quite a while already, as indicated by Table 1, below:

Table 1 near here

This table shows that the populations of 'developing countries' have been affected by climate disasters between 42 times and 114 times more than that of 'developed' nations, generally increasing through time. The types of climate disasters increasing in developing nations include (a) variable and uncertain rainfall (drought and flooding), (b) many more deaths for females than males, (c) risks being transformed into vulnerabilities as insurance cover deteriorates, and (d) cyclones and hurricanes. These problems especially adversely impact on developing nations since they are most dependent upon agriculture for their existence, tend to exist in the tropics and sub-tropics, and have far lower levels of social insurance.

In the developing areas there are fewer resources to adapt through dikes and other means of (for instance) physically reducing the impact of rising sea levels; and they are affected far out of proportion to their contribution to climate change. These factors, the UNDP Report (2007:ch2) recognises, are going to continue to adversely impact on their relative and absolute levels of human development. Major climate impacts will retard health infrastructure, increase the incidence of diseases such as Malaria, and reduce levels of government finance for education and nation-building. In essence, this is a problem of circular and cumulative causation (see next section), since less human development leads to even less human development, sometimes in unpredictable ways. In the future this impact will get worse, as Cline (2007) shows, since while most areas of the world will get much hotter, it is primarily the 'developing' areas in the tropics and sub-tropics which will have much less precipitation as well, generating low agricultural output.

However, the climate change reports mentioned have not adequately explored the extent to which these contradictory core-periphery forces are structurally related. (They are also relatively indifferent to the fate of non-human species.) In discussing 'developing' and 'developed' areas the reports fail to recognise the strong network, power and corporate relationships that link varying degrees of underdevelopment of the periphery and overdevelopment of the core, with differential results in the semi-periphery. The core nations are the most powerful, the periphery includes the weakest, while the semi-periphery has intermediate power relative to the rest. There are strong connections between the social and environmental costs being felt in the periphery and the relatively lower costs born by the core. To comprehend these relationships we need to situate climate change and environmental destruction within the global circular treadmill of production which generates ecologically unequal forms of exchange, several forms of metabolic rift, and serious injustices.

The core–periphery contradictions associated with climate change are multiple yet dialectically interrelated, since they are associated with the social and environmental costs of the treadmill of production. Capitalism is a system built on accumulation, expansion, innovation and profit. It ‘naturally’ seeks to caste aside barriers to its powerful motion through expanding on a world scale, destroying pre-capitalist systems, introducing new methods of production, creating new needs and wants, and discovering new forms of energy and minerals to enhance its circular and cumulative motion of reproduction (Schumpeter 1911, Marx 1857-58). In the process it generates new forms of competition as well as changing concentrations of economic power. It exploits resources as much as possible, including labor power, soils, trees, animals, minerals, forms of energy, winds, weather patterns and anything else that will stimulate accumulation and profit. It generates new forms of credit and finance to stimulate this creative pattern of destruction. It seeks out new areas and populations to exploit in its incessant drive for growth and expansion.

In the process, however, it does generate numerous social and environmental costs, as Polanyi, (“disembeddedness”), Kapp (“social costs”) and Georgescu-Roegen (“entropy”) pointed out. Indeed, these costs are structurally linked to the search for profit, since if the costs were internalised into accounting techniques and prices, it is unlikely that the system could generate sufficient profit and investment for expansion. But the costs cannot always be easily calculated, and certainly not in market prices, since the market is imbued with numerous forms of power and authority which mask the costs and destructions inherent in such motion. Core elements of these costs are linked to the concept of metabolic rift. As Foster (2000, 2009) has argued, Marx used this notion based on his research which drew on various forms of exploitation emanating from the social and spatial unevenness of its motion. One element of this metabolic rift is the recognition that the generation of wealth and use value is dependent upon the creative exploitation of labor power through transforming it into labor exertion in the production and reproduction of goods and services. There is thus a transformation of use-values in the circuit made possible by the exertion of human potential, through stimulating the creative force of human beings as they live, sleep, eat, and yet return back to earn their keep in the circuit. Capital can exploit labor unrepentantly if a continual supply is forthcoming, such as when the reserve army is large, or with the movement of ‘surplus’ labor from the countryside to the town and cities, or when low-wage workers are mobilised for capital through the global system. But otherwise there is a limit to capital since it must ‘enable’ labor power to be suitably replenished so that it can be exploited every day through the treadmill of production.

Metabolic rift also applies to capital gaining material resources from the periphery for use in the core. Here there is a continual process of exploiting soil, energy and resources from the countryside and producing capital and consumer goods in the towns and cities. This transfer of materials and energy tends to develop the core while it exhausts the periphery through soil degradation, exhaustion of minerals and energy, biomass depletion of fish, cattle and wildlife, and modification of climate. Soil degradation of the countryside is inextricably linked to the pollution of the towns and cities, the extraction of scarce natural fertilisers in the periphery is necessary for replenishment of soils in the core, and the importation of cheap natural resources and food from the periphery has historically enhanced the industrial development of the core. The metabolic rift of dead and deteriorating workers when the reserve army is high is analytically similar to the degradation of the soil and terrain for the benefit of imperial countries, which constitutes the transfer of high-quality energy and materials from the periphery to the industrial centres of the core and semi-periphery. In short, the uneven global and regional impact of climate change and ecological destruction is structurally linked to the accumulation requirements of powerful business interests, and without these critical social and ecological costs, accumulation and profit would likely cease to operate as required (see Hornborg 2006).

Sociological political economists have also been developing the notion of ecologically unequal exchange to help explain these global contradictions and injustices. Jorgenson et al (2009:263), for instance, demonstrate that the "vertical flow of exports is a structural mechanism allowing for more-developed countries to partially externalize their consumption-based environmental impacts to lesser-developed countries." The terms of trade plays a role here in tending to undervalue minerals, agricultural output and to some degree mass production manufactures from the periphery while enhancing the value of high-technology goods and high-skill output from the core and semi-periphery. What has been called the 'ecological Prebisch-Singer hypothesis' postulates that the periphery provides materials, labor power and energy to support the development of the core and semi-periphery. In the process the periphery suffers the negative social and ecological costs of soil degradation, deforestation, and the entropic unavailability of resources. This also negatively impacts on industrial development potential, standard of living and quality of life. The core is simultaneously saved many of these social and environmental costs through cheap resources from overseas, lower levels of domestic ecological waste, and being able to protect their own environmental space.

The structure of international trade, foreign direct investment, and commodity chains thus generate a contradictory series of processes as resource and labor exploitation of the periphery contribute to the material advancement and quality of life of the core nations and areas.[13] Jorgenson (2009) demonstrates how unequal power relationships encourage the use of foreign direct investment in the periphery in ways that enhance

[13] Clark and Foster (2009) study a specific example of unequal exchange enhancing the primary accumulation of capitalism, as labor and resources were exploited unsustainably through Guano and nitrate imperialism, which stimulated global metabolic rift. Complex relationships between Peru, Chile, Britain, China and the US saw long-term transfers of economic value in the nineteenth century through exploitation of accumulated bird droppings (Guano) and labor. Core nations were thus able to replenish their supply of soil nutrients through unequal exchange of materials and labor from the periphery to the core.

polluting and ecologically inefficient processes such as deforestation and water pollution (which negatively influence human health). Hornborg (2009) argues that the use of international market prices hides the unequal flow of biophysical resources in the form of embodied labor, land, matter and energy, as the social and environmental costs of the global system of production and trade are hidden from view. A zero-sum game is seen to be in operation as this system of power largely supports business and consumers in the core at the expanse of the periphery.

James Rice (2009) scrutinises the role of agency in these structural forces as powerful corporations enhance their accumulation and profit, core workers seek higher wages and better conditions, and strong states try to accommodate workers and corporations through the treadmill of production. Formal transnational agreements and organisations also play a role through the World Trade Organisation, the North American Free Trade Agreement, and the International Monetary Fund. Asymmetric power relations are thus institutionalised into these institutions and agreements through the drain of surplus labor and energy/natural resources from the periphery to the core. The semi-periphery plays an important role as it "possess[es] international exchange advantages over peripheral countries … even as semi-peripheral countries are subject to unequal exchange in relation to the core" (p. 223).

The climatological and ecological significance of the circular treadmill generating metabolic rift through ecologically unequal exchange is considerable. For instance, after the second-world war global imbalances started to become significant as the core consumed more resources than it produced. This tendency has continued into the present. John Shandra et al (2009) provide empirical evidence that poor nations exporting masses of raw materials to core nations have higher levels of mammals under threat of extinction or unsustainably low levels of supply, while core nations with higher income levels per capita have lower levels of threatened mammals. Jorgenson (2009b) found that transnational corporate FDI in less developed countries stimulates total and per unit carbon dioxide emissions, and is thus relatively less ecoefficient. Richard York et al (2009) examined the ecological footprint for China, India, Japan and the US over 1961-2003 and found that while each nation obtained more economic output per unit ecological footprint, due to increased scale their footprint declined in all cases. This paradox arises out of reduced carbon intensity along with increasing carbon emissions as core and semi-peripheral nations are expanding their domestic consumption through grander lifestyles and conspicuous emulation that speed up the transformation of low into high entropy.

In a series of articles and books, J. Timmons Roberts and Bradley C. Parks have examined the significance of these asymmetric power relations for questions of justice and new social movements. At the core of their argument in *A Climate of Injustice* (Roberts and Parks 2007) is the empirical fact (cited above) that mostly it is the core advanced nations that have the highest per capita levels of greenhouse gas emissions, while the nations of the periphery have the lowest emissions but the highest incidence of extreme climate events and catastrophes. Some emerging nations have high absolute levels of greenhouse gasses (such as China) but relatively low per capita emissions. These inequalities and contrasting power relations generate differential visions and distrust among the players involved in global climate change policy. Inequality thus engenders non-cooperation as those with the most power eschew responsibility and those with the greatest extreme events have little bargaining power, major social costs and entropy degradation.

The death and destruction in the periphery are ongoing while the core and parts of the semi-periphery continue to benefit through cheap materials and labor power from the periphery. Global resentment is garnished as the south expects the north to reduce their consumption, while the north expects the south to make adjustments to reduce the extreme events and greenhouse gas emissions. Distrust generated by inequality, power differentials and divergent worldviews is the main reason Parks and Roberts (2008) posit major problems in creating a post-2012 global climate accord. The north will necessarily have to massively assist the periphery in any global accord that may be forthcoming, if some effective reciprocity, trust, shared worldviews and negotiated forms of justice are to succeed in generating agreement. Central to the vision of Roberts and Parks (2009) is the core thesis of the ecologically unequal exchange theory that the core owes the periphery an ecological debt for the environmental damage embodied in energy and materials transferred to the north from the south, which is the cause of much of the inequality underlying global distrust and the lack of an effective climate change regime.

5. Principles of Circular and Cumulative Causation and Uncertainty

Every aspect of climate change and ecological destruction through the treadmill of production and metabolic rift involve numerous processes of circular and cumulative causation (CCC). It is now time to introduce this concept formally, and to relate it specifically to the social and environmental costs of business. The principle of CCC is a critical one for political economy, drawing from (among many others) the traditions linked to Thorstein Veblen, Gunnar Myrdal, Nicholas Kaldor, K William Kapp and Nicholas Georgescu-Roegen. CCC includes two processes, the first being the interaction between *multiple variables*; and the second being the tendency for the variables to interact in a *cumulative manner* generating dynamic motion, periodic instability and irreversibility through historical time. (See Berger 2008b, 2009 for details.)

In a CCC fashion, we examine the linkages between three interrelated (open) sub-systems of habitat and species; human activities (including the circular treadmill); and climate change. These are shown below in Figure 3 (2004 data; IPCC 2007c:105):

Figure 3 near here

Five main factors involved in the circular treadmill have adversely impacted the ecological environment since the industrial revolution, and especially during the 1970s-2000s. Land-use clearing and other activities associated with agriculture and forestry (contributing 30.9% of GHG emissions) left the soil devoid of critical nutrients and naked whole areas of land; as did human population settlement and housing. Transportation and building (21% GHGE) along with Industry (19.4%) exacerbated the process, as did energy supply (25.9%). Wastes also played a role (2.8%). These five commercial and consumption activities reduced the stock of ecological resources, especially flora for photosynthesis and oxygen production, and fauna which provided useful fertiliser and seed-distribution for the reproduction of flora. Atmospheric systems were also changed.

These factors coevolved into climate change trends. As this occurred entropy expanded and thus reduced the energy and matter available *for use* by human beings and other animals and plants.

Historical evidence demonstrates that these CCC effects generated anomalous climate events, such as greater unevenness of climate tendencies, increased heavy precipitation events, more regular heatwaves, increasing tropospheric water vapour, declining glaciers in the Arctic region and Greenland, more acidic oceans, and rising sea levels (IPCC 2007a). Looking to the future, various scenarios have been formulated depending on the likely levels of temperature change. Some of the more obvious changes link to likely successive increases in temperature from 1ºC through to above 5ºC, bearing in mind uncertainty levels and uneven changes throughout the world.

There are various scenarios corresponding to different long-term temperature changes, including uncertainty ranges (Stern 2007:66-67; IPCC 2007a:66). For instance, if by 2100 global average temperatures rise by 1.4–3.1 °C (specific estimate 2.1 °C), with CO^2-e around 450ppm, then 'minimum' damage to the environment is said to be likely. However, even this optimistic outcome is fraught with anomalies as likely the Greenland ice sheet will have begun irreversible melting, between 15-40 percent of species face extinction, 40-60m people are likely to be exposed to malaria in Africa, there is likely to be a 20-30 percent cut in precipitation to certain areas, a major drop in crop yield is probable in tropical regions, and around possibly 10m people are predicted to be affected by coastal flooding. On the other extreme, with no attempt to mitigate greenhouse gas emissions, average temperatures are expected to rise by between 3.2–7.8 °C, leading to around 700-900ppm of CO^2-e by 2100. At this level all major ecosystems are likely to be in crisis, mass extinction is probable, catastrophes common, the Himalayan glaciers destroyed, fish stocks seriously diminished and dozens of major cities under water. Several scenarios exist in between these possible outcomes.

In an open system, changes in greenhouse gasses will likely affect climate in non-linear and cumulative ways, since there are several feedback processes between the major variables. Some of the key CCC changes in this regard are as follows, as discussed in the various climate reports:

- *Non-linear Threshold Effects*. Extreme weather patterns are hypothesised to operate, especially beyond certain temperatures. However, the periods in which the threshold effects come into play are uncertain. While some extremes are already happening, these are thought to be much more pronounced beyond, say, a 2ºC increase in global temperatures since 1990 (*above* 450-550ppm $C0_2$-e concentrates). These threshold effects include major increases in global temperatures, major variability of temperature (including many more heatwaves and frosts), heavy rainfall events, major droughts and flooding, more tropical cyclones, major bushfires, and extreme winds (Garnaut 2008: 40). Another threshold point is said to possibly emerge at increases of above, say, 3ºC, so that any success in mitigating these higher excesses would be crucial for reducing the even more catastrophic impacts. The IPCC (2007a) also discusses the possible increase from 4 to 5ºC (since pre-industrial times) as being "much greater than the consequences of moving from 2 to 3ºC" since, for example, "hurricane damage increases as a cube (or more) of wind-speed, which itself scales closely with sea temperatures" (p. 59).

- The Stern Review (2007:60) demonstrates these CCC effects in terms of heightened costs as climate change accelerates (especially beyond 450-550ppm Co_2-e). For instance, it discusses floods and droughts increasing exponentially; a small increase in temperature accelerating the frequency of extreme events (a convex curve); passing into the threshold effects propelling "increasingly negative" impacts on crop growth (an inverse parabolic "hill function"); a "sharp increase in mortality once human temperature tolerances are exceeded"; infrastructure damage from storms "increas[ing] as a cube of wind speed"; and "costs of sea-wall construction increase[ing] as a square of defence height".[14]

Uncertainty is critical to these CCC effects. The work of Frank Knight (1921), J.M. Keynes (1921, 1936), and G.L.S. Shackle (1970) have laid the ground-rules of this analysis, and some environmental experts have taken this further. Risk is where a challenging element is calculable and fairly determinate, such as the throwing of a dice, or the chance of being hit by a car in an automobile accident. But uncertainty is where there is relative ignorance, or concerns the distant future when knowledge is lacking or ambiguous. The less weight of evidence we have for a specific phenomenon, the greater the uncertainty associated with a specific probability, and the earlier we have to respond to the problem. The informational anomalies associated with greenhouse gas emissions and climate change generate deep uncertainties. These uncertainties are exacerbated by CCC dynamics generating complex dynamics, social costs, entropic irreversibilities, and periodic instabilities along the lines drawn by Kapp (1978:ch 4), Georgescu-Roegen (1971:121-122) and Foster (2009:ch 10)

Climate change uncertainties relate to the lack of knowledge about key ecological, behavioural and modular relationships as they change through historical time. The extreme weather events and catastrophes linked to threshold impacts ("tipping points") are the greatest source of uncertainty. At these crucial tipping points rapid escalations will occur in critical environmental processes that radically upset the climate, producing a whole series of catastrophes (IPCC 2007b:chs 6,19, Keller et al 2008, Lenton et al 2008). The key idea underlying threshold effects is that a small change can have major impacts, in a circular and cumulative fashion. Some of the tipping points may already be happening, such as coral bleaching. Serious threshold effects in the future are likely to be linked to West Antarctic ice-sheet disintegration, weakening and potential collapse of thermohaline circulation, El-Nino changes, and Greenland ice-sheet melting.

All of the threshold effects have some element of nonlinearity, hysteresis and irreversibility as feedback processes change parameters, thereby producing cumulative effects. The uncertainty relates to the timing or states (multiple) when the changes and effects manifest *suddenly*. The complexities involve a multifarious linking of numerous variables that are difficult to predict. Threshold effects are important because they

[14] All four of the studies (IPPC, Stern, UNDP and Garnaut) assume equilibrium analysis in terms of the eventual calming down of impacts, when mitigation is effective (see also US NSTC 2009). However, this equilibrium terminology is questionable due to "pervasive" uncertainty built into the systems; a medium-term (pragmatic) view shows that no equilibrium of CO_2-e occurs in any of the scenarios; and the assessments make very strict assumptions about the parameters, which are unlikely to prevail. Usage of circular and cumulative causation is a better framework of analysis.

challenge the idea that climate change with bring linearly related impacts on the system. Threshold effects are likely to happen sooner than linear models predict, and Keller et al (2008:5) argue that "only subtle warning signs" are likely in many cases "before climate thresholds have been crossed" due to "multiple parameter" interaction (see McInerney & Keller 2008:29).[15]

CCC necessarily leads to greater uncertainty. This is because the greater the number of factors considered the more uncertain is the result. For instance, Keller et al (2008) describe climate change as being "deeply uncertainty" due to the complexity of the phenomena. Complexity is due to the involvement of models used, ecological processes and behavioral variables. Modular uncertainty involves initial conditions, boundary conditions, parameters, structural factors and subjective factors. Ecological uncertainties include radiative forcing, ocean heat uptake, winds and currents, climate sensitivity, and complex feedbacks. Behavioral uncertainties involve investment, technology, social relationships, population, consumption and governance. With all these mostly unknown variables uncertainty increases, thus heightening the degree to which greenhouse gasses need to be reduced in the immediate future. With deep uncertainty the main factor promising to reduce uncertainty is timely decreases in greenhouse gasses. Thus the more circular and cumulative the processes the greater the uncertainty and the more urgent is the need for changes in social behavior and organization to limit climate change.

The more circular and cumulative the processes become also the more problematic becomes the relationship between stocks and flows of GHG. This is because once the stocks of emissions rise to a higher plateau due to multiple processes the longer it will take for reductions in flows to affect stocks. As Knutti et al (2008:5) recognizes, the "temperature response of the system is determined by the stock of atmospheric greenhouse gasses, rather than the flows represented by annual emissions". Knutti emphasizes the importance of ignorance about core processes such as climate sensitivity, cloud formation, and absorptive capacity of the seas leading to "intractable uncertainty".

Multiple processes, greater uncertainty and large lags between stock-flow changes support the case for "stabilization" at a 300ppm Co_2 (≈400ppm Co_2-e) level, especially influenced by the work of James Hansen. Many climate change analysts have joined a recent call for the 300ppm CO_2 long-term stabilization level, compared with 2007 levels of 385ppm, due to the likely earlier tipping points. As the global mean surface temperature, global ocean temperature, sea levels, Arctic sea ice melting, ocean acidification and extreme climate events are increasing much earlier than expected, "at the upper boundary of the IPCC range of projections" (Richardson et al 2009:6), the circular and cumulative impacts are impinging stronger than expected. As James Hansen et al (2008:228-229), for instance, argue:

> Humanity today, collectively, must face the uncomfortable fact that industrial civilization has become the principal driver of climate change. … Paleoclimiate evidence and ongoing changes imply that today's Co_2, about 385 ppm, is already too high to maintain the climate to which humanity, wildlife, and

[15] Lenton et al (2008) have studied most of the above threshold effects, interviewing experts and assessing the evidence.

> the rest of the biosphere are adapted. … Continued growth of greenhouse gas emissions, for just another decade, practically eliminates the possibility of near-term return of atmospheric composition beneath the tipping point for catastrophic effects.

Within this context of rapid cumulative causation and multiple feedback between processes that are often not included in the models (loss of Arctic sea ice, extinction of interdependent species and ecosystems) there is the likelihood of very rapid changes towards not only *tipping points* but also *points of no return* (path dependence). In this context, it is timely to embed in the analysis the contradictions elaborated by Polanyi, Kapp, Georgescu-Roegen and Foster concerning the disembedded economy, social costs, entropy and cumulative causation and uncertainty. This reinforces, in a political-economic context, the importance of systemic changes in replacing the circular treadmill of production with more embedded social, political and economic practices.

6. Conclusion

This paper has related core principles of political economy to the problem of climate change. It started with the principle of historical specificity to situate patterns of climate change through the history of planet Earth, paying special attention to waves of warming and cooling during the Phanerozoic, Pleistocene and Holocene eras. The most recent history of climate change is the only one generated by anthropogenic influences, and it is likely to have even more catastrophic impacts into the future. The principle of contradiction showed that market capitalism has been reproducing the circular treadmill of production at the expense of the ecological environment through disembedded tendencies of escalating social costs, entropy and destructive creation. Major changes in social and ecological organisation are required to prevent path dependent destruction of ecological resources and processes becoming too extreme.

In this context, the principle of uneven development is instructive, since the periphery (which is not contributing to major climate change) is being and is likely to continue to be much more affected than the core (and semi-periphery) into the future. This is because most of the periphery lies in the tropics and sub-tropics and because of the structural linkages between unequal exchange of resources and labor between periphery and core. These unequal forces generate distrust, divergent visions of justice and lack of accord between core and periphery, while the circular treadmill of production exacerbates the inability to resolve climate change problems.

The principle of circular and cumulative causation centres on the interaction of multiple variables and feedback loops that magnify the atmospheric extremes. These cumulative results also relate specifically to the principle of uncertainty, since the major uncertainty is how quickly climate change will destroy/upset core elements of ecological resources (including atmospheric patterns and ocean currents). Deep uncertainties generate problems especially when tipping points are scrutinized. Likely major threshold effects will emerge suddenly, with only subtle warning signs, hence earlier than expected, which will necessitate more serious efforts at environmental preservation, even while entropy continues to generate waste even in a steady state system.

The principles of political economy enable one to gain a holistic view of the climate change problem. It seeks to explain the historical origins of the problems, the role played by institutions in its perpetuation, the core impact of contradictions involving the vested interests against the commons, uneven development between core, periphery and semi-periphery, the role of multiple factors and cumulative effects, as well as uncertainty and sudden impacts. Political economy can be seen as a critical part of an ecological economics perspective, albeit broader than the usual one applied to the problem.

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