Examining Effects of Climate Change Impacts on the Ramsey-Cass-Koopmans Growth Model

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Abstract

This discussion paper provides a broad understanding on climate change and its likely impact on the economic growth, with particular emphasis on the rescaling of consumer utility and its effect on savings rate in an economy. As evidence of climate shifts become more apparent, so are techniques in estimating the likelihood and magnitude of damage caused by the changing climate, leading to calls for urgent and strong action on mitigating the rate of change. These calls for mitigation have been met with criticism from the other side who propound that benefits of mitigation do not outweigh the cost of lost economic growth. It is argued here that as market goods become more abundant resulting in non-market goods being scarcer, the rescaled consumer preferences, which are reflected in prices, result in a new economic composition. The discussion on economic impact is illustrated using the Ramsey-Cass-Koopmans growth model where savings rate is a key parameter in determining economic growth and rate of return on capital.

Keywords: *Anthropogenic climate change; economic growth; discount rate.*

A cynic knows the price of everything and the value of nothing.—Oscar Wilde

Introduction

The Stern review on *The Economics of Climate Change* (2006) has come to symbolize somewhat of a landmark event leading to introduction and appreciation of the climate change issue by the global community as a whole. However, actions to mitigate the impacts of climate change have been too few and far in between to have any meaningful impact.

This seemingly callous response by the global community, particularly in major parts of the developed world is a manifestation of prioritizing domestic interests over global concerns. One key reason for marginalizing this issue with probable catastrophic impact is that it is, for some, eclipsed by cost-benefit trade-off. Since the most severe impacts of climate change will be felt in the future –because of the inertia in the global atmospheric system and natural "elasticity" of global ecology to counterbalance changing forces for a limited period; this coupled with perhaps obstinately important and deeply embedded notion of continuing economic growth has sparked criticism of the Stern review by prominent personalities from the economics and policy making areas (Dasgupta 2006; Nordhaus 2007; Weitzman 2007). Most of the criticism revolves around the use of low discount rate which seemingly exaggerates the present value of damage. Critics argue for use of a higher discount rate as indicated by growth rates, savings and expected market rates of return. This is in line with the neoclassical assumptions that view environmental resources as stock of capital whose exploitation is limited by technology and labour factors. Implicit in the opposition to action on climate change is the assumption of perfect substitutability between natural and man-made goods (Nordhaus 1994). In their analysis of endogenous economic growth, Aghion and Howitt (1998) point out that the main types of capital inherited by succeeding generations which lead them to have higher living standards than their predecessors are physical and intellectual capital, despite the degradation or loss of natural capital. They however, note that the substitutability between natural, physical and intellectual capital, is low.

On the other hand, Pearce and colleagues (1990) make a strong argument for conserving natural resources. In their opinion the substitutability between man-made and natural capital is limited, and the emphasis should be on preserving natural stock. Daly and colleagues (1992) view natural and man-made capital as compliments to each other and find that natural and man-made goods share poor substitutability. That is, no amount of increase in man-made goods can offset or compensate for the loss in biodiversity or increasingly polluted air. Lack of consensus does not extinguish important questions that remain unanswered: how much should we care about future generations? How can we be sure that economic growth is guaranteed for future generations? Will that growth continue at a pace that will make future generations richer than we are? How do we value differential and distributed impacts of climate change effects on people?

The main discussion point in this paper is to present the latest findings from climate change science and explore its impact on the Ramsey-Cass-Koopmans growth model. Based on the seminal work of Frank Ramsey (1928), David Cass (1965) and Tjalling Koopmans (1965) worked independently to extend the Ramsey growth model to include intertemporally optimizing consumers (which later came to be known as Ramsey-Cass-Koopmans model). The Ramsey-Cass-Koopmans model provides excellent insight into capital accumulation and investment, which form a basis for more advanced endogenous growth models which have emerged since the 1980s.

Discussion of Key Climate Change Findings and Impacts

The entire range of climate change impact is too wide to be addressed in this paper. For the purpose of illustration and simplicity, only the effects which are likely to have a more "direct" impact on the Ramsey-Cass-Koopmans growth model are discussed here.

Increase in greenhouse gas (GHG) emissions upset the thermodynamic equilibrium of planet earth. Since all life, including human beings, has evolved over several millennia to adapt to this equilibrium point of the planet, sustained deviation from the equilibrium is certain to adversely impact life as we know it.

Precipitation Changes

Increase in the global average temperature is expected to be linked to changes in rainfall (Allen and Ingram 2002) which can throw out of balance the available water supply for humans and agriculture. Radical changes in precipitation lead to lack of availability of basic resources such as water and can have disruptive effect on economic activity in the affected regions. Long-term rainfall decreases have been observed in large regions including the Mediterranean, central and southern parts of North America, and southern Africa (Trenberth et. al. 2007; Zhang et. al. 2007; Gao and Giorgi 2008). More recently over 52% of United States was declared to be affected by drought (Drought Monitor 2012), noting that both the magnitude and extent of drought were exceptional.

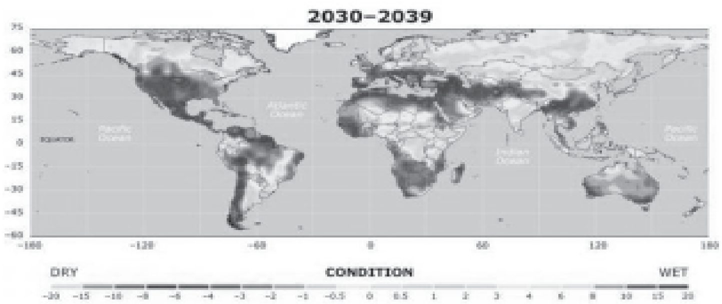

Figure 1: *Observed deviations from normal precipitation measures over the stated period.*

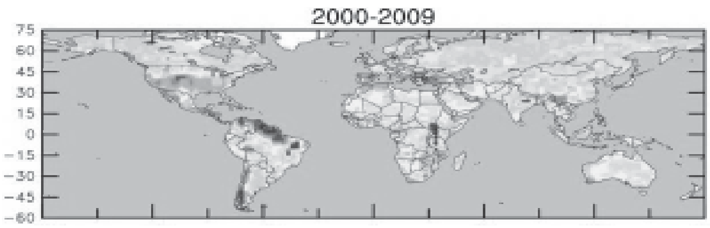

Figure 1 & Figure 2 *(immediately above): chart the Palmer Drought Severity Index (PDSI) based on the combination of empirical and projected data. Readings below-4 is considered severe drought and can indirectly affect the density of human habitation by determining the cultivability of land. Credit: National Centre for Atmospheric Research (NCAR). Projections are modeled on Intergovernmental Panel on Climate Change's (IPCC) "moderate" scenario.*

Noteworthy observations can be made from NOAA and NCAR precipitation models (shown in Figures 1 and 2). For instance, it can be clearly observed that even with significantly large reductions (per the "moderate" scenario) in GHG emissions, the precipitation patterns will be altered leading to flash floods increasing run-offs, diminished soil moisture and increasing heat-waves among others. That is, even when it rains after prolonged periods of dryness it may be so intense that it will be counterproductive. The overall change in hydrological cycle would be accompanied by changes in streamflow, humidity and contrail-aided cloud formation. This would likely result in an increase of precipitation in the higher latitudes and diminishing precipitation in the subtropics and middle-latitudes.

Impact on Agriculture & Food Ecology

Perhaps the most important short-term concern from a human perspective is our ability to feed ourselves. Much of agriculture around the world depends directly on climatologically determined phenomena such as timely rain, atmospheric temperature, soil moisture, humidity, run-off etc. Dependency on timely occurrence and stability of these phenomena is even higher in developing countries. Dai and colleagues (2004) found that the fraction of global land experiencing very dry conditions increased from about 15% in 1970 to almost 30% by 2002. The increase in the fraction of land under very dry conditions has been accompanied by an increase in surface air temperature near land areas along with increase humidity levels. This would be in-line with modeling of atmospheric physical conditions with increases in GHG concentrations leading to increase in atmosphere's heat retention capacity. The changes in precipitation and humidity combined with tropical belt widening towards poles (Seidel et. al. 2008) suggest lower yields from farming.

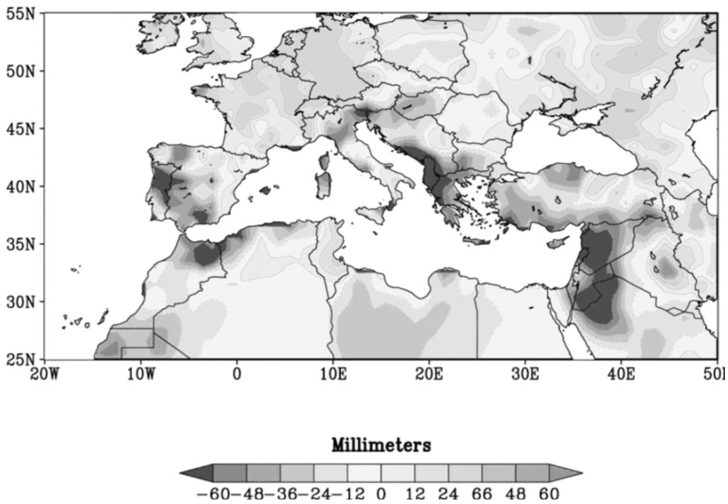

Figure 3 *: shows that from 1971-2010 the Mediterranean region experienced significantly drier winters in comparison to 1902-2010 period. Credit: NOAA*

The UK Meteorological Office[1] estimates that rice yield would decline on average about 10% (kg/ha) if the average temperature increases by 2°C and precipitation increased by 20%; the decline would increase to 14% for the same increase in temperature with 20% lesser precipitation. These modeled estimates are not adjusted for regional severity and post adjustment may pose higher level of risk. For instance, a large part of north American agricultural area in the southwestern region could be lost to "permanent drought" by 2050 (Seager et. al. 2007). Seager and colleagues have modeled the precipitation scenario for a "moderate" case of emissions reaching around 720 ppm[2]. Much of the Seager and colleagues' findings have been corroborated by the US Geological Survey's Climate Change Science Program (CCSP) (2008) and state that there is high probability that southwestern parts of North America could face permanent drying. Such a loss would increase food insecurity across the globe since much of the current high yield "corn belt" would be subject to dust bowl phenomenon. As soil loses moisture it loosens and in combination with high speed winds and land use change gives rise to dust storms. Increase in frequency of dust storms in a well known, largely arid landmass such as Australia is an evidence of increasing surface warming. Australia is known to be experiencing dust storms with potentially increasing frequency since the last decade[3].

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[1] Source: http://www.metoffice.gov.uk/media/pdf/3/c/precis.pdf (accessed: Sept 5, 2012)

[2] As per the latest Scripps Institution for Oceanography data the CO_2 concentration in atmosphere stood at 394 ppm as of July 2012.

[3] Source: http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=40274 (accessed 03/12/2011).

With about 9 billion people to feed, Tilman and colleagues (2011) estimate that world food demand could go up by as much as hundred percent by 2050. To sustain present level of per capita food consumption an estimated 1 billion hectares of new land has to be brought under cultivation, which most often risks the tropical rain forests further destabilizing natural carbon sequestration cycle. Sheridan and Bickford (2011) find strong evidence that many species are already exhibiting smaller size in regions where effect of climate change is higher. This finding is in-line with the fundamental ecological and biological principle that relates to biomass development. Similarly, aquatic species that are exposed to higher acidification and calcification disturbance in combination with hypoxia have noticeably lower biomass in recent years. On a continued trajectory, these and more ecological changes from anthropogenic climate change will have strong and lasting impact on the way we feed ourselves.

Sea Level Rise

Our oceans are pivotal to maintaining the overall carbon balance of the planet. Advances in Atmospheric-Ocean General Circulation modeling (AOGCM) show that in recent decades they have been instrumental in providing a 'buffer' effect (in relation to atmosphere) for delaying the full warming effect of excess carbon emission. One well understood phenomenon is that warming causes oceans to expand and sea level to rise (Bindoff 2007). Additionally, loss of land ice is expected to contribute to sea level rise. Rapid loss of land ice have recently been observed in Greenland (Rignot and

Kanagaratnam 2006) and Anatartica (Pfeffer 2008). Latest satellite records of Greenland ice melt have been particularly concerning (NASA 2012). The feedback loops of rate of thawing needs to be accounted for to estimate the potential warming from newly unlocked carbon sinks. Improvements in modeling techniques show that rate of sea-level rise will not be the same everywhere (Sallenger 2012). Sallenger and colleagues present strong evidence that the Atlantic coastal region of North America is experiencing three to four times faster sea-level rise than global average. Since the trend is expected to continue in coming decades it means loss of some of the most valuable real estate assets. Estimates of sea-level rise range between 1 to 2 meters by year 2100 (Pfeffer 2008). More recent findings estimate sea-level rise due to ice melt to be far higher in matter of centuries (Dutton and Lambeck 2012). Corroboration with paleoclimatic data demonstrate link between large contributions of ice sheet loss to sea-level rise (Hansen 2007; Oppenheimer 2004). A meta-assessment of studies and results suggest that global sea-level rise could be anywhere between 0.2 to 0.6m per degree of warming (Meehl 2007).

Extreme Weather Events

Over the centuries of anthropocene, mankind has had a significant impact on the climate and ecology to varying extents (Crutzen 2002). Owing to system inertia and buffer delays, it is extremely difficult to establish a conclusive link between extreme weather events and anthropogenic warming at this stage. However, integrated assessment models (IAM) indicate an accelerating increase of probability of extreme weather events as warming continues (Durack and Wijffels 2012). This would translate into much higher damages from hurricanes, tornados, flash floods, and droughts among others.

Nature of Climate Change: Irreversibility & Tipping Points

Perhaps the most important reason effects of climate change are hard to perceive by the masses is the natural variability of the weather. Effects of changing climate are markedly different from the natural variability of weather, as frequency and bias of variable weather are "loaded" towards warming patterns. During the initial decades of change, a person may recognize changes in climate over his lifetime (given long enough life and good memory). Changes in the overall planetary climate systems are weak in the beginning and cannot be noticed without scientific measuring techniques. It provides time for action and mitigation; however, it also means that delayed action is useless as some thresholds would be crossed making climate change largely irreversible (Solomon 2008). More complex phenomena such as anthropic forcing, permafrost decay rates, cascading thresholds and self-amplification are difficult to model (Tedesco 2011), but are understood to impact baseline scenarios negatively.

Impact on Ramsey-Cass-Koopmans Model

Potential impact on overall utility and consumption

The advent of climate change can introduce a number of complications into the Ramsey-Cass-Koopmans model.

For instance, in a large, diverse economy the intra-country representative agent framework could weaken due to differential impacts; the same can be extended to sector-wise changes.

$$U = \int_0^{\infty} u\ (c_\tau)\, e^{n\tau} e^{-\rho\tau} dt = \int_0^{\infty} u\ (c_\tau)\, e^{-(\rho-n)\tau} dt$$

The above equation shows the simplified definition of aggregate household utility at time 0. where,

c, denotes per capita consumption, and $c_t > 0$

ñ, denotes pure time rate of preference

n, denotes the number (of households)

u, denotes the utility as a function of consumption

With respect to utility, Inada conditions are assumed to hold:

$$\lim_{c \to 0} u'(c_\tau) = \infty \qquad \lim_{c \to \infty} u'(c_\tau) = 0$$

Consider for the sake of clarity, that climate change is an exogenous occurrence whose effect is to rescale utility. Using the above equations surmising a fixed level of income from which to draw total utility, consider a stylized two-good economy where income can be spent either on market goods, giving rise to U_{MG}, or on non-market good, to satiate U_{NMG}. In the current context the term ‘non-market goods’ is a generic reference to ecosystem services and commons access.

Simulating utility functions using the constant relative risk aversion (CRRA) function (Ref. chart 1) as described in the Dynamic Integrated model of Climate and Economy (DICE) (Nordhaus 1994) can be useful in providing a 'big-picture' assessment of utility curve.

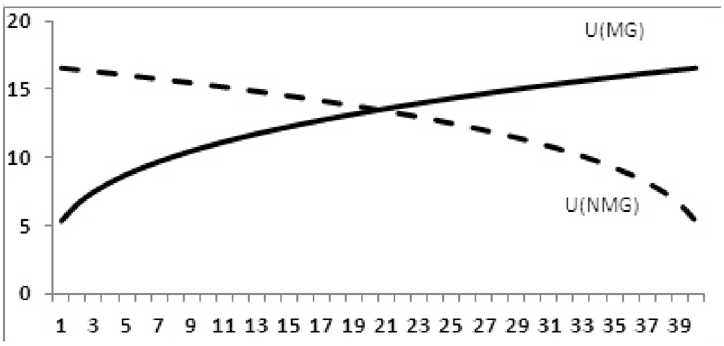

Chart 1 *shows simulated utility curve projections in a stylized two-good economy.*

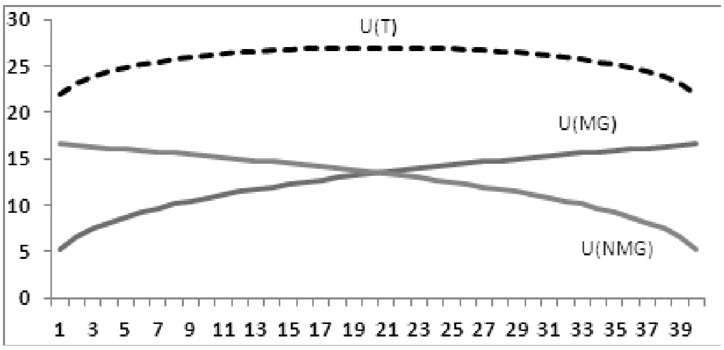

Chart 2 *shows simulated total utility curve projection vis-à-vis the utility curve from loss of non-market goods (ecosystem services) and declining utility from increasing consumption of market goods.*

The total utility curve is a function of individual utilities arising from consumption of market and non-market goods. Given that CRRA accounts for differential elasticity of marginal utility of consumption from the two different types of goods: the rate of decline of ecosystem services leads to greater loss of utility vis-à-vis increase in consumption of market goods. The U_T maxima point signifies maximum utility obtained from consumption of market goods and maximum tolerable loss of non-market goods; beyond which point disutility increases.

This means that as the overall warming, ô, increases, in (1) the overall utility at the societal level for the same level of consumption has been rescaled upwards.

Effect on Savings Rate

As households save they accumulate stock of assets. Since the savings can take place primarily in two forms: physical capital and pecuniary, it is assumed that one is a perfect substitute for the other. Thereby the rate of return, r, for both must be equal.

On a per capita basis, the same can be represented by:

$$\frac{da}{dt} = a_t = (r_t - n \quad a_t + w_t \quad c_t$$

where,

r_t, denotes rate of return

w_t, denotes the wages

a_t, denotes the assets

Climate change reduces the marginal productivity of physical capital thereby decreasing the expected r_t. At the prospect of lowered returns consumers may decide to reduce the quantity saved, that is, increase consumption. The overall effect is a decline of accumulated capital stock which likely will have a direct bearing on technological development (Mankiw 1992).

Conclusion

The impasse between the issue of efficiency and sustainability is similar to one set of economists advocating descriptive approaches and others adhering to prescriptive approaches. While consumer utility preferences play key role in determination of descriptive (high) discount values or prescriptive (low) discount values, most of the analyses focus on production possibility set born out of substitutability debate.

It has been widely acknowledged that everyday impacts of anthropogenic climate change are becoming more noticeable in scientific domain (Oreskes 2004; Anderegg 2010) and gradually trickling down to public domain (NOAA 2012). As shorelines and glaciers recede, increasing warming is certain to result in scarcity of vital ecosystem services and thereby reconstitute preference matrix of consumers.

This discussion paper presents an overview of impacts of climate change which is almost certain to lead to changes in consumer preferences and highlights the impact on utility as projected in a simplified economic construct. The prevailing neoclassical establishment is largely of the view that imperfect substitutability can be overcome by technological means so that substitutability (ergo sustainability) can still be achieved in the face of resource depletion. However, presence of poor substitutability in utility function with respect to market or production goods and ecosystem services renders the technology argument moot and can have serious adverse consequences on welfare and health even assuming unlimited consumption of production goods. The Ramsey-Cass-Koopmans model of economic growth has consumption, and consequently, savings rate as its cornerstone for analysis. In a warming world, with consumer preferences shifting towards sustaining consumption of vital necessaries, the savings rate is likely to decline thereby straining economic growth. Choosing to delay mitigation of warming would imply greater costs in the future. Leapfrog technological improvements are not only necessary to mitigate climate change impacts, but the rate of improvement should be higher than the net effect of diminished marginal productive capacity of existing capital and the required rate of growth at the aggregate level.

A more comprehensive and policy-relevant analysis necessitates correction of outcome for Pareto optimality and key approaches to commons management at a global level. Further, analyzing future growth in a market based economy would require detailed understanding of how this growth would be distributed, especially in the lower stratum of society. Acknowledging that consumers derive utility not only from man-made goods but also from ecological services such as clean air and plentiful water would only lend stronger support for mitigating climate change in the present.

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