CHARLES UNIVERSITY
FACULTY OF SOCIAL SCIENCES
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Bachelor Thesis

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The Economic Impact of Climate Change

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Abstract

After the industrial revolution, one of the biggest components of the energy production has been the greenhouse gas emissions which in depth is a substantial factor for production of nearly all goods and services.

Whether it is agriculture, mining, transportation, oil refinery, manufacturing or providing services, one of the least expensive ways to produce has been through the combustion of fossil fuels. Households, firms, farms, and many other economic agents emit some amount of greenhouse gases.

Undoubtedly, productions that has involved usage of greenhouse gases, fossil fuels and carbon emissions have proven to be one of the most effective ways to allocate resources until it comes to one's realization that one of the greatest externalities of the time, the climate change, has been a consequence of greenhouse gas emissions and combustion of fossil fuels.

Climate change has been claimed to be one of the largest, most devastating, most complex, and most uncertain challenge threatening the environment than any other environmental problem that has previously been experienced by human beings.

However, the scope and extent of the impacts of climate change differ significantly throughout different studies, which might be as a result of different methodologies, approaches and assumptions undertaken to answer complex questions posed by this phenomenon. Even though there exists a consensus on the aggregate long-term consequence of climate change in the upcoming centuries, the uncertainties emerge from the facts that some predictions about the future consumption and weather patterns are largely based on weak and strong assumptions, because there might not exist an alternative method to approach the matter.

Hence, one of the questions that arises from the general study of climate-change impacts on global economy is that whether there exist some short-run positive consequences of global warming on some particular regions of the world, (which studies show they do) and if so, then to what extent will these consequence contribute to offsetting long-term negative effects and whether is it even a good idea to take the short term positive effects into consideration when the issue is being studied, policies are being made and approaches are being evaluated to tackle the long term impacts of climate change.

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Introduction

Evidence that changes in climate have both biophysical and economic consequences are growing rapidly, and not only will these consequences exist in the future, they are expected to become more severe, particularly by the end of this century. Many studies have concentrated on the nature of the future events and have attempted to predict the severity of them, although with different amounts of uncertainty.

In this thesis the answer to one particular question will be pursued: when it comes to the economic impact of climate change, whether there are any positive outcomes of climate change in the not so distant future and if so, which are those and can those outcomes contribute in off-setting the long-term negative consequences.

To begin with, firstly the main global consequences of climate change will be introduced in Chapter 1 that will affect the world economy as a whole and further in the chapter, the economic sectors that are most affected will be discussed in details, and the different estimations with regards to the potential damages will be presented as well as the methods on how they estimations were concluded.

Furthermore, in the second chapter of this thesis, the economic impact of climate change on particular regions will be illustrated since it makes sense to assume that not all parts of the world will be affected in the same manner. Following that, the winners and losers will be determined and by then it will be evident whether some regions' gains can contribute to the others' losses.

The third chapter will take into account certain variables such as GDP per capita, trade and urban population that are assumed to be the most important contributors to the growing level of carbon emissions.
The chapter will focus on the data gathered from high and medium income countries and see whether the impact of the above-mentioned variables on carbon emissions are significant and whether the pattern of GDP per capita growth has historically followed the Kuznets curve in these countries.
Following the historic data analysis, the policy consequence for different regions will be presented in the next chapter. The predictions that have been made by different studies will be point to and the impact of both, taking immediate action and continuing in the "business as usual" scenario, beyond the year 2060 as well as the scope of uncertainties that under-lie in these predictions, will be explained.
Furthermore, the impact of climate change on economic indicators such as aggregate output and inflation will be discussed.

Finally, the last chapter of this thesis will discuss the issues surrounding the climate finance, the challenges that countries and regions face when it comes to implementing the pledges, what are those pledges and how different regions have agreed and obligated themselves to prevent severe future damages and what are the role of institutions such as the International Monetary Fund.

Taking all of this into account, the aim of the thesis, using empirical evidence, will be to illustrate the economic impact of climate change on the economy, both in the short and long-run and to try to find out whether there had been or will be any positive benefits of the phenomena that can offset the outcomes that awaits the world by the end of the century particularly in the case of inaction.

Chapter 1
Modelling the Consequences

1.1 Main Global Consequences of Climate Change

Studies have identified the physical risks of the climate change as changes in precipitation patterns, shifting deserts and monsoons, sea level rise, more intense and extreme weather, destruction of marine food chain due to ocean acidification as well as changes in ocean circulations.

To be precise, after the Paris summit in January 2016, one study by the staff members of the IMF*(Mai Farid, Michael Keen, Michael Papaioannou, Ian Parry, Catherine Pattillo, Anna Ter-Martirosyan, and others, 2016)* concluded that in the absence of mitigation and adaptation policies, it is anticipated that global temperatures will rise by 3-4 C◦ until 2100 as carbon dioxide (CO2) concentrations have increased from 280 parts per million [1] to 400 ppm until 2013, meaning that carbon emissions have increased from 2 Billion metric tons from 1900 to 32 billion metric tons in 2013 and it is anticipated to further grow 700-900 ppm until 2100 which will result in a 0.07% - 0.09% concentration of CO2 in earth's atmosphere.

Data show that a third-fifth of CO2 emissions are committed by the developing countries and an extra 5 billion metric tons of CO2 is generated due to deforestation and the consumption of non-CO2 greenhouse gases (methane and nitrogen oxide) which have increased the CO2 equivalent concentration to 440 ppm – although the concentration had previously remained to 300 ppm for 80,000 years.

Due to the rise in the concentration of CO2 in the atmosphere, temperature in average has increased by 0.8 C◦ since 1900 and if the concentration

increases by 450, 550 and 650, temperature will rise by 2.0, 2.9, and 3.6 C◦ respectively.

Another study by *(Wietzman 2011)* suggests that in absence of mitigation, ,with a probability of 22%, temperatures will rise by 6 C◦ and with a probability of 5%, it will rise by 10 C◦ (by the end of the century) which will result to 2-3% fall in the total world GDP to which lower income countries (LICs) are most vulnerable, and besides that, for developing countries also, there will be catastrophic effects on agricultural output, forestry, coastal real state and tourism.

Furthermore, *(Burke, Hsiang, Miguel and others 2012*) found during their research that the actual unmitigated impact of the climate is 5-10 times more than the current provided estimates; meaning that the fall in world GDP will account for 15-20%.

Nearly, all studies conclude that LICs will be affected severely and in particular, sub-Saharan countries (SSA), Middle-East and Northern Africa (MENA) will be the worst effected regions facing lower labor productivity and health issues due to rising temperatures, drop in agricultural output and water scarcity.

Following that, countries like the USA, UK and China are those who are assumed to be moderately affected; for example, in the USA, a fall in labor productivity is thought to be offset by the increase in tourism business and in China, there seems to be an initial short term positive effect of the climate change as rising temperatures affect crop growth positively.

Lastly, European countries are perceived to bear the least negative impact of the climate change. Even though some southern countries may face challenges

1- Currently, the concentration of (CO2) in atmosphere is 400 ppm which means 0.04% of the earth's total atmosphere.

(Earth's atmosphere is consisted of 78.09% nitrogen, 20.95 % oxygen, 0.93 % argon, 0.04% CO2 and the rest 2% is water vapor and other gases)

1.2 Main Impacts on Economic Growth

Climate change does not only have extensive effects on main economic areas such as agriculture, energy and healthcare, but will also affect the supply of and demand for goods and services in all the sectors of economy, with different measures of intensity.

Studies mostly try to assess the aggregate economic impact of climate over a certain period of time using the Integrated Assessment Model (IAM) which basically uses impacts on different sectors of the economy and further aggregates the result of the change as a whole and uses it to re-valuate the total impact on welfare and make projections, however comparing data from different regions and making a certain specific projection overall is somewhat difficult and therefore, some studies use the Computable General Equilibrium models which is used to examine implications of climate change on specific economic sector by using a comparative static approach.

"CGE models focus on the relations between different economic actors and contain a full description of the economic system using multiple economic sectors: households supply production factors (labor, capital, land) and consume goods and services, while firms transform the production factors, with intermediate deliveries from other sectors, into the output of goods and services. In a multi-regional CGE model all economies are linked through international trade. For assessing climate change damages, the detailed description of the economy allows for a detailed representation of those impacts of climate change that are primarily affecting markets, such as changes in crop yields, health expenditures, labor productivity and energy demand.

IAMs focus more on describing the interactions between the economic and biophysical system, i.e. how economic activity leads to environmental pressure, and how environmental feedbacks affect the economy. Many IAMS that have been

used for policy advice (such as DICE) are highly aggregated and contain only a cursory description of the economy. Other IAMs have much greater detail in the description of the biophysical system, often at the expense of lacking feedbacks from the biophysical system to the economy. The more stylized nature of IAMs make them more suited to describe a wider range of climate change impacts in an aggregated fashion." (OECD 2014)

The Economic categories that will be affected mainly as a result of climate change are:

1- Agriculture: this category includes effects on crop yields, changes in livestock due to exposure to heat or cold (i.e. mortality and morbidity), changes in fisheries and so on
2- Coastal Zones: changes in land ownership and possible destruction of land and capital from sea level rises, hurricanes and floods
3- Extreme events: mortality and labor productivity
4- Health: mortality and morbidity from exposure to heat and cold, diseases and infections
5- Energy demand: energy demand changes for cooling and heating
6- Tourism demand: changes in flows of tourism and touristic services
7- Water Stress: changes in energy supply
8- Human security: migration and possible human conflict

In **agriculture**, studies that have been conducted to comprehensively evaluate the global effects of climate change conclude that there is a negative impact on overall global agriculture due to the changes in regional temperatures and water precipitation, particularly in crop yields, livestock, pasture and range land and aquaculture, however on a regional level, there are some positive and negative effects varying across the different regions. Precisely, positive effects are generated due to the changes in rainfall, CO2 concentration and ozone concentration. In fact, one study by the OECD in 2013 showed that in some regions of the world,

the higher concentration of CO2 in the ozone layer will stimulate the corps yields initially and in extremely cold areas, the temperature rise will result in higher labor productivity, but the as the concentration of ozone increases, eventually the effects on yields become negative.
With regards to the fisheries, another study (Ahlheim and Frör, 2003; OECD, 2014) showed that fisheries in developing countries specially in tropical areas will be severely affected by the changes precipitation pattern, monsoon shifts and sea level rises, while on the other hand, fisheries in developed countries which are located in the northern latitude will actually benefit from it.

Coastal Zones, comprised of ecosystem (beaches, cliffs, etc.) and human system (food production, settlements, ports), almost surely will be negatively affected and will lose land and capital as well as food production resources due to precipitation patterns change, sea level rises, ocean acidification, salt water intrusion, coastal erosion and increases in storms.

Extreme events are river floods in tropical areas, hurricanes, long droughts as a result of reduced rainfalls and increased evaporation in non-tropical areas. These extreme conditions will generally affect the physical capital (factories, houses, roads, bridges, energy infrastructure, machineries and so on) as well as land, and due to these threats, an outflow of physical and human capital and labor will result in macroeconomic costs such as permanent low levels of GDP and economic growth for that particular area. (low levels of GDP may also depend on initial stocks of physical capital and labor)

Effects of climate change on **Health** may not be easily evaluated since there are market and non-market costs associated with this category, the market costs include the decrease in labor productivity due to diseases

and infections and therefore less labor contribution to the overall production while on the other hand, the non-market costs include the pain and suffering.

The effects on **demand for energy and tourism** are more or less equally distributed such that when it is feared that the demand for cooling in summer will increase significantly and the demand for heating systems will decrease, at the same time, regarding tourism, the shifts in weather patterns will make some areas less attractive for tourists while other areas might become more attractive some an aggregate impact in the short term is not very obvious however it certainly can be concluded that regions who benefit from coastal area tourism will severely see a drop in the business, while areas that were previously completely covered by snow or ice might be shaped to a more favorable form.

One of the other severe impacts of climate change is projected on the ecosystem, changes in precipitation patterns and rises in the sea levels in general will cause migration of birds and fish towards the north pole, heat will generally decrease human productivity and thus less production of food supply might be noticed and also severe heats will cause erosion of trees and therefore, a decrease in supply of raw materials may be seen. So, as a result of impacts on ecosystems, economic sectors such as production of raw materials, supply of food, fisheries and forestry may be affected most severely.

It must be mentioned that many of these risks indicated above may not necessarily happen all at once, nor there is certain amount of concrete evidence that they will affect in the same manner as it has been predicted, since many of the predictions contain some amount of uncertainty, however, once the risks associated to the categories above are positively

correlated as a result of rising temperature, then these risks might combine and the probability of them happening together might rise as well.

Modelling Framework

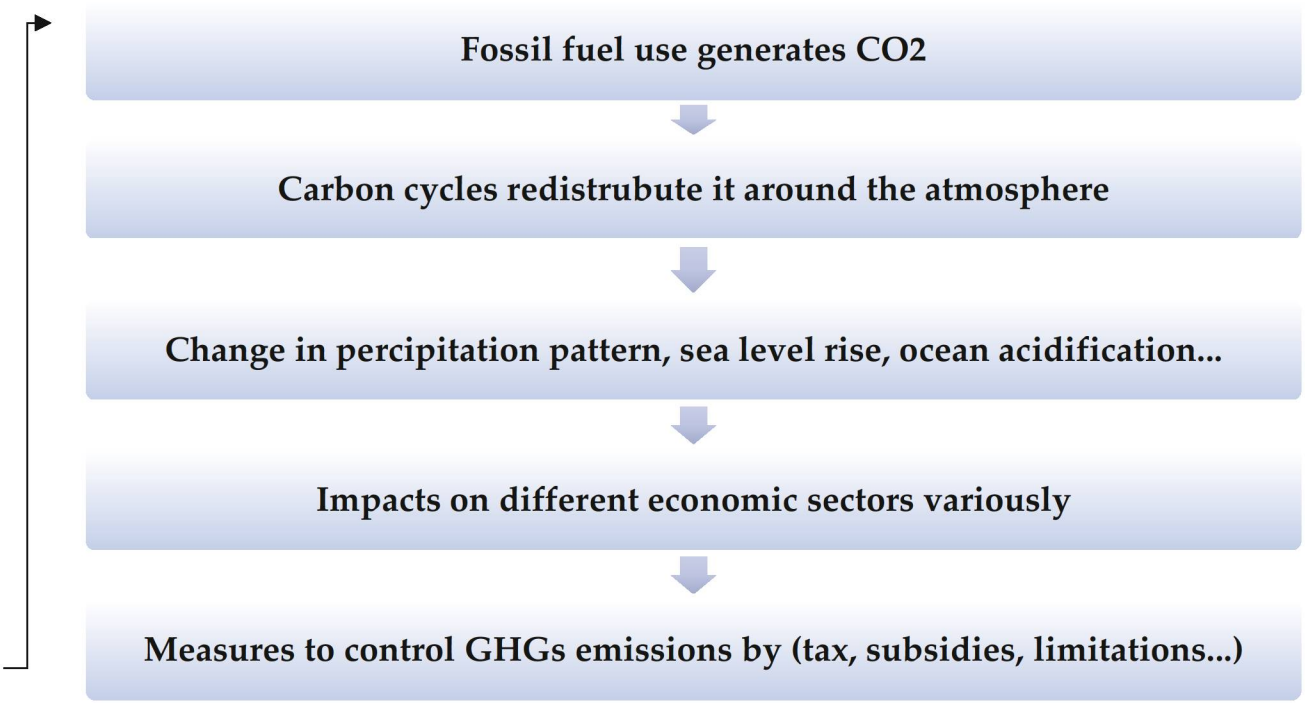
1.3. An introduction to DICE model

In order to have a particular approach towards answering effects of climate change on economy, certain models need to be used to portray a more mathematical and scientific view of the issue. In this section, the Dynamic Integrated Climate Economy (DICE) will be introduced and used for calculating data as well as measuring the current and future impacts of climate change on economy.

The DICE model is simplified analytical and scientific model which represents economy, policy and scientific aspects of climate change, the model was first developed by William Nordhaus in 1990 and is until today used for making projections about future effects of carbon related consumptions on the economic growth and total social welfare.

The model views the impacts of climate change from a perspective of **neoclassical economic growth theory,** in this theory, economies make investments on technology, education and capital which decreases consumption today in order to increase consumption in the future. Taking that into consideration, the DICE model views the concentration of greenhouse gases as negative natural capital and attempts to reduce the impact of emissions today as investments which will reduce both consumption today and the future harms caused by the consumption of GHGs

Figure1.1 A Flow chart of modules and logical structure of the DICE models.



In general, the Integrated assessment models can be used for two main purposes, the first will be the policy optimization and the second is policy evaluation. Policy evaluation model generally are recursive or equilibrium models that generate paths of important variables but do not optimize an economic or environmental outcome.

Policy optimization models have an objective function or welfare function that is maximized and can be used to evaluate alternative paths or policies. In models that have an economic structure, the objective function is generally a measure of economic welfare.

The DICE/RICE[2] models are primarily designed as policy optimization models, although they can be run as simple projection models as well. In both modes, the approach is to maximize an economic objective function. The objective function represents the goal implicit in the problem. For the

2 - Regional Integrated Climate Economy

DICE model, the objective function refers to the economic well-being (or utility) associated with a path of consumption.

There are two main uses of the optimization: First, from a positive point of view, optimization is a means of simulating the behavior of a system of competitive markets; and, second, from a normative point of view, it is a possible approach to comparing the impact of alternative paths or policies on economic welfare.

Equations in DICE Model:

The assumption in the DICE model is that the world in general and regions specifically have well-defined preference and that is represented by a general *welfare function.* This social welfare function is increasing in consumption per-capita in each generation and in population with a diminishing marginal utility in consumption per capita.

The DICE model also assumes that the consumption is a generalized consumption while not only includes the market goods and services but also non-market goods and services such as leisure, health, environment and so on.

$$(1) \qquad W = \sum_{t=1}^{Tmax} U(c(t), L(t)) * R(t)$$

Equation (1) shows a mathematical representation of the fact that policies are chosen to maximize general welfare where W, is the discounted sum of the population-weighted utility of per capita consumption. The notation is that c(t) is per capita consumption, L(t) is population as well as labor inputs, R(t) is the discount factor and all of them are a function of time t.

The utility function in the DICE model is assumed to be a constant elasticity utility function:

$$(2) \quad U[c(t), L(t)] = \frac{L(t) * c(t)^{1-\alpha}}{1-\alpha}$$

This form assumes a constant elasticity of the marginal utility of consumption, α. (In the limiting case where $\alpha = 1$, the utility function is logarithmic.) The elasticity parameter is best thought of as aversion to generational inequality. Put differently, the elasticity represents the diminishing social valuations of consumption of different generations. If α is close to zero, then the consumptions of different generations are close substitutes, with low aversion to inequality; if α is high, then the consumptions are highly differentiated, and this reflects high inequality aversion.

And finally, R(t) can be described as the discount factor for the welfare of different generations and the in the equation below:

$$(3) \quad R(t) = (1 + \rho)^{-t}$$

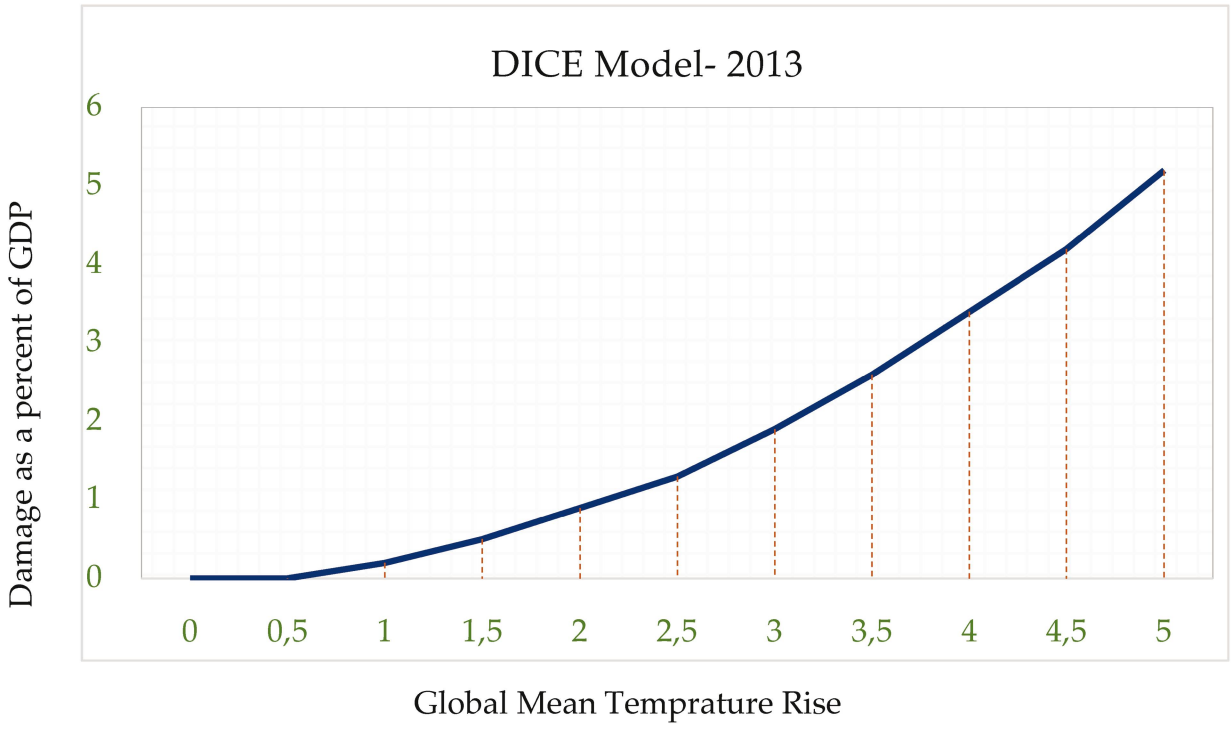
Where ρ is the discount rate for the economic well-being preferences of the future generation.

It should be mentioned that the equilibrium in the DICE model is interpreted from a conceptual point of view representing the outcome of market and policy factors as they currently exist. In other words, the baseline model is an attempt to project from a *positive* perspective the levels and growth of major economic and environmental variables as would occur with current climate-change policies. It does not make any case for the social desirability of the distribution of incomes over space or time of existing conditions. (Richard. SJ Tol 2011)

Details about the variables of the above explained model is provided in the Appendix 1 of this thesis.

The DICE-2013R model explicitly includes a backstop technology, which is a technology that can replace all fossil fuels. The backstop technology could be one that removes carbon from the atmosphere or an all-purpose environmentally benign zero-carbon energy technology. It might be solar power, or carbon-eating trees or windmills, or some as-yet undiscovered source. The backstop price is assumed to be initially high and to decline over time with carbon-saving technological change.

In the full regional model, the backstop technology replaces 100 percent of carbon emissions at a cost of between $230 and $540 per ton of CO_2 depending upon the region in 2005 prices. For the global DICE-2013R model, the 2010 cost of the backstop technology is $344 per ton CO_2 at 100% removal. The cost of the backstop technology is assumed to decline at 0.5% per year. (See Appendix 1 for details)



Source: DICE/RICE Model – Nordhaus 2014

Figure 1.2 - Estimates of the Impact of Climate Change on the Global Economy

Chapter 2

Regional Impacts

2.1 Regional Macroeconomic Effects

Effects of climate change differ across the regions in the globe, researchers have concluded that not all regions will be paying the costs similarly and not all of this burden will be shared equally (Paris Accord 2015). While many findings from different studies tend to converge to the notion that economic growth and the consumption of fossil fuels have shown a positive correlation through the contemporary history, studies conducted by the OECD conclude that this growth will follow a **Kuznets curve**, thus, the consequences of carbon emissions after some point in the future, will start having negative impacts on the economic growth of many regions.

An attempt to study the historic relationship between carbon emissions and growth in GDP Per capita across high, middle and low-income countries has been made in the next chapter, but initially some of the most prominent findings of globally consequential studies will be pointed to in the following paragraph.

A detailed research by the OECD suggests that, following the Central General Equilibrium model, the worst regions affected by 2060 and beyond will be mainly in Africa and Asia.

In particular, GDP losses in 2060 will amount to 3.3% for Middle-East and Northern Africa, 3.7% for South-and South- East Asia and 3.8% for Sub-Saharan Africa, respectively.

The reason why the above-mentioned regions will be affected worst is that they are of the world's poorest regions and they do not have the capacity to deal with the consequences as it might be needed and on the other hand, they are very highly populated. It is also worth mentioning that up until 2040 these regions will somehow follow a similar trend of negative impacts but beyond that year, the divergence of South and South-East Asia will begin, meaning, the negative impact will be increasing more rapidly for this region, compared to the other two.

The projected GDP losses for the Latin American regions by 2060 is estimated 1.5% by 2060 and Asia and the Rest of the Europe will on average face a -2.0% GDP growth by the same year which includes China and the Russian Federation as well. (OECD 2014)

Moreover, for the same year, the OECD projects that OECD Europe, OECD Pacific and OECD America will very likely have a negative GDP growth however not by the same rate as the other regions mentioned above. (-0.2%, -0.3%, -0.6% respectively)

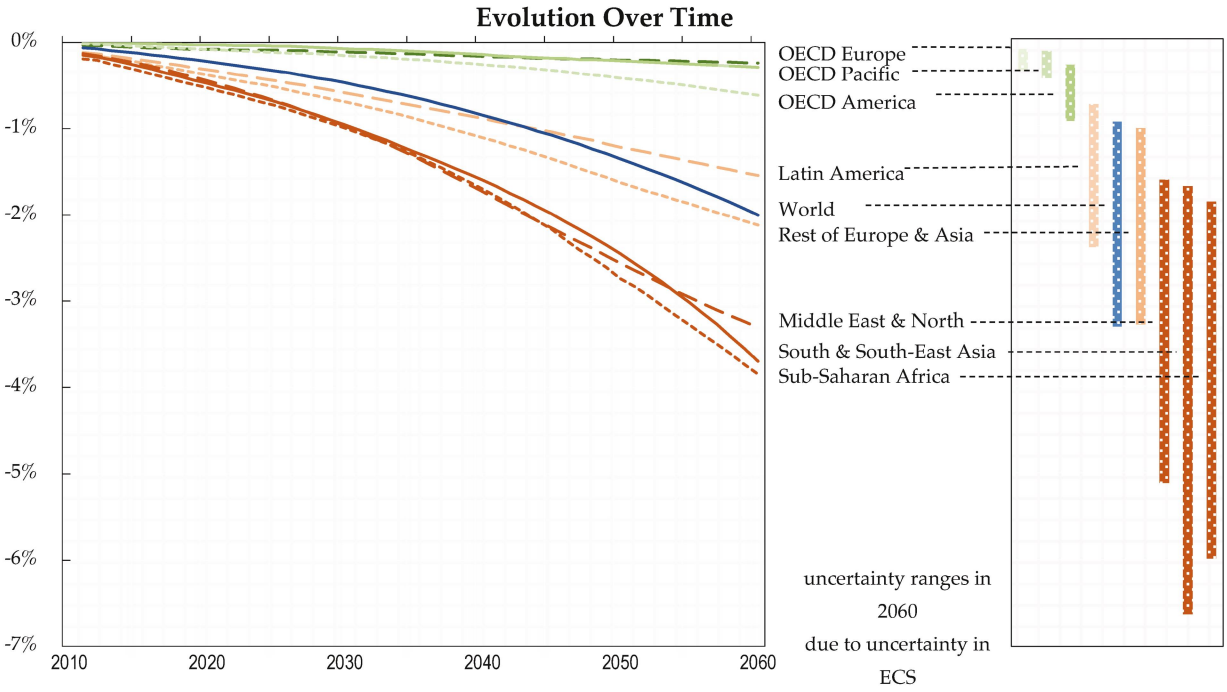
It is worth mentioning that the OECD report provides these numbers with some level of uncertainty, after all, forecasting accurately the GDP of a region for almost half a century does seem quite optimistic.

The uncertainty underlies in the inability of measuring the level of climate sensitivity of the regions precisely.

Nevertheless, the moral of this research lies in the fact that with some standard deviation from the mean, all regions will start facing negative GDP growth at the current trends of fossil fuel and carbon emissions. A detailed discussion for at least four main regions vulnerable to environmental risks, namely the Indian Sub-continent, Africa, Europe, Ocean and Islands will be provided further in this chapter.

Figure 2.1 – *shows projected negative GDP growth by 2060 for 8 regions and an aggregate for the world, taking into consideration the uncertainty that arises from environmental climate sensitivity. "ECS determines the eventual warming*

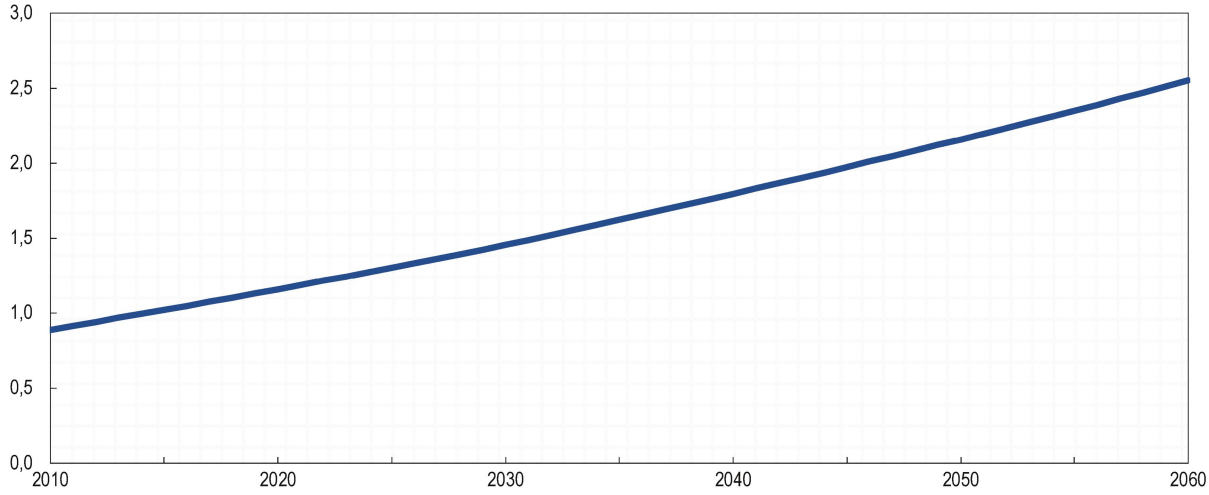
in response to stabilization of atmospheric composition on multi- century time scales" (IPCC 2013)



Statistical Source: ENV Linkage Model - http://dx.doi.org/10.1787/888933275982

The Intergovernmental Panel for Climate Change (IPCC) suggests that in case carbon emissions are doubled, an estimated 3 degrees Celsius average temperature growth will be observed as a result, the estimation varies between 1.5 to 4.5 degrees Celsius under uncertainty and 1 to 6 degrees Celsius under a wider ranged uncertainty level, therefore the central projection suggests a 2.5 degrees Celsius temperature rise (from the pre-industrial average) by the year 2060.

Figure 2.2 – shows the global mean temperature increase predicted by IPCC up to 2060



Statistical Source: ENV-Linkage model, http://dx.doi.org/10.1787/888933275975

As it can be seen in Figure 2.2, the average global temperature rises linearly during the fifty-year period (with some uncertainty), however this needs to be pointed out that the economic impacts of this rise will follow a non-linear trend during the same period, and the consequences of temperature rise will not be proportionate with the effects on many economic factors especially for the most vulnerable regions, in other words, the biophysical effects become more and more severe during the period.

The non-linearity exists due to three main factors, firstly, the losses that arise from agricultural yield (excluding for the temperate zones where initial impacts are either positive or non-existent up to a certain threshold) are by no means in proportion to the average temperature rise. Secondly, nonlinearity arises from the limited possibilities in the economy to adjust to changes in factor supply and productivity. For small changes, reallocations within sectors and regions, and between regions, are relatively easy, but for larger shocks the reallocation costs become increasingly high. Third, those regions who are having a higher and more rapid rate of GDP growth and whose share in world GDP is rising, will sustain higher losses due to the rises in average temperature, which

implies that there will be a shift in the weight of different regions in the average global GDP rise and therefore, there arises a non-linearity in global damages, and finally, some of the damages in the capital stock, such as coastal damages have permanent economic effects, which implies that up until 2060 these damages may show smaller effects but will clearly follow a non-linearity after that period.

Again, due to high uncertainty, it is very difficult to provide an actual scenario based on some precise percentage. Nonetheless, the OECD projects on average a 2% GDP loss by 2060 which ranges between 1% to 3.3%. Therefore, any projection is best described as "best guess" by the organization.

A list of uncertainties that exist in every stage of calculating the impact of climate change are listed in the box below.

Box-1 – Uncertainty in damage projection

1 – Uncertainty in projecting the key socio-economic growth drivers
2 - Uncertainty in projecting the key factors of production for energy
3 – Uncertainty in projecting the intensity of emissions
4 – Uncertainty in projecting regional patterns
5 – Uncertainty in projecting impacts on specific economic category

Now that the uncertainties in projection of climate damages has listed, it needs to be pointed that damages not only vary across the regions but also across economic sectors for those regions.

The latest survey conducted by the Working Group II of the Intergovernmental Panel on Climate Change (IPCC 2014) estimated the

"global aggregate economic loss" between 0.2% up to 2%, and that this threshold will be reached by 2060. With slight differences, popular economic studies namely Nordhaus (2014), Weitzman (2013) and Dietz and Stern (2014) nearly conclude the same results, although much of their predictions are for the whole century rather than fifty years which is discussed here. The main point is that the conclusion of all of them indicate that losses in East-Asia and Africa are more severe compared to the high latitude countries such as Russia, which initially benefits from climatic change in sectors such as agriculture and tourism, but it is worth commenting about that most of these studies tend ignore a key variable while studying effects on different regions. In such a globalized world, the trade factor and the effects of it on climate change is not something exogenous and is worth paying attention to.

Trade as a key determinant of global economic growth is one of the variables which will be analyzed later, to see whether there are actual significant effects of it on carbon emissions, whether they have actually shown a negative or positive impact on carbon emissions.

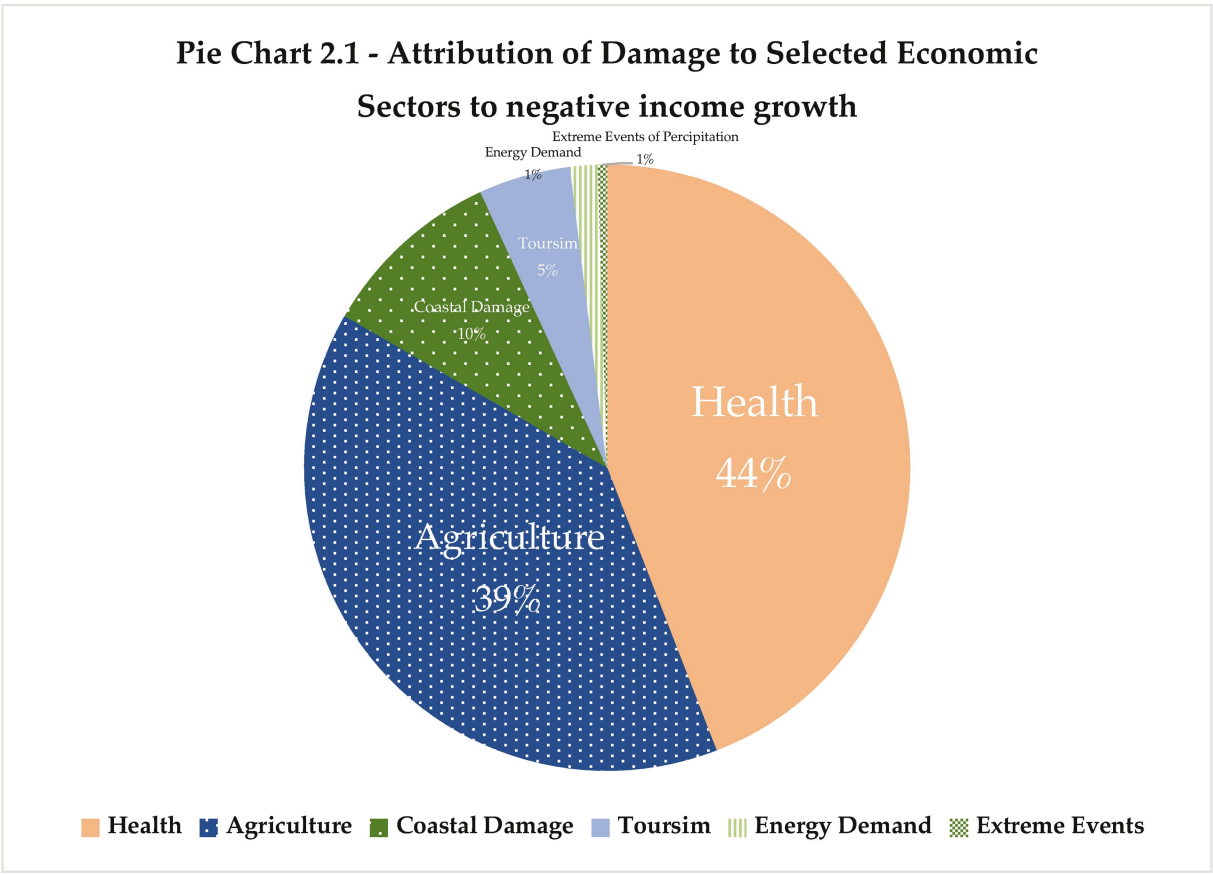
Moving on with the sectorial effects, the impacts on the health and agricultural sectors contribute most to the economic growth and particularly, until 2020, impacts on human health will dominate the contribution, by 2060, the health impacts contribute to 0.9% GDP loss in the central projection. This dominance of labor productivity losses from occupational heat stress is also found in e.g. Roson and Van der Mensbrugghe (2012) and Ciscar et al. (2014), while studies that show a dominance of agricultural impacts tend to exclude heat stress effects (e.g. Bosello et al., 2012; Bosello and Parrado, 2014). It is also estimated that at current rate of fossil fuel emissions, between 2040-2060, the health damages will increase up to less than twice while at the same time range, agricultural damages increase to three times, (agricultural damages also

include fisheries).

Thereby, by 2060, the contribution from agricultural damages will lead to negative economic growth of 0.8%. This estimate however does not include effects of CO2 fertilizations, but it is necessary to mention that the assumption behind this calculation is that food security itself is not under threat, that even in case of extreme agricultural damages, global trade will offset the threats imposed by food security as it is thought to be strengthening over time. Assessment of food security however, is not something within the scope of this thesis.

The projected contribution of coastal damage and tourism decline as a consequence of climate change is estimated 0,2% and 0,1% respectively and is predicted to be increasing between the years 2040 up 2060 as the effects from the damaged capital become permeant, while decrease in energy demand and damages from extreme events of precipitation (hurricanes and floods, etc.) will have almost somewhat negligible effects. Furthermore, the consequences of heat stress on humans and heat stress on crops are all accounted for as a part of agricultural damage. The share of each sector is further illustrated in the Pie Chart 2.1.

Pie Chart 2.1 - Attribution of Damage to Selected Economic Sectors to negative income growth



Source: OECD – computed in MS Excel

2.2 Regional Consequences

It is not worthless to discuss in this part how impacts on the above mentioned economic sectors vary across different countries and regions around the world. As expected, due to the large regional differences with different economic structures, the results vary substantially and we must focus on where the economic consequences of these selected sectors have the largest and smallest impacts.

Out of 25 regions of interest (divided regionally and country-wise by OECD), 22 of them which represent 94% of the world economy and where 97% of the world population lives, are affected negatively, at least to some extent, by the impacts of climate change on these six selected sectors.

A dominant sector which is negatively affected in these areas is health, nevertheless, many other regions will suffer from consequences of coastal damage beyond 2060. On the other hand, tourism might show different outcomes in different regions because of the nature of climate change, meaning that some of the coldest places might become more attractive than those areas that currently possess a high market share in tourism business, at the same time, the linkage in international trade between the biggest losers and the unaffected (or winners) make the impacts seem to fluctuate across different regions differently.

Figure 2.3 demonstrates the damages by regions and impact category by 2060 and as it can be seen there, the worst affect places are India, sub-Saharan Africa (which excludes South Africa), Northern Africa, the Middle-East and some other developing Asian countries.

Particularly in India, agricultural losses are substantial because the increase in temperature in a hot country like India affects both heat stress on humans as well as yields in corps, and in general the labor

productivity. No severe impact on tourism and energy demand can be seen for the country, although (Akpinar –Ferrad, Singh 2010) argued for the positive effects due to high demand in Indian markets for cooling, but that impact to a very large extent is offset by the reduction in demand for warming in the Indian markets.

In sub-Saharan Africa, the same argument can be made regarding agricultural losses as for India. Losses in crop yields, heat stress to humans and loss of productivity are main factors that contribute to agricultural damage in this region. Meanwhile in the Middle-East and Northern Africa, the outcomes for agriculture and health look to be nearly close to India and sub-Saharan Africa, while there are also high risks of coastal damages due to sea level rises, but coastal damages will worst distress the developing Asia where most of the capital stocks are concentrated in coastal areas.

As it can be seen in Figure 2.3, there are only two countries which will observe a positive impact of climate change by 2060, namely, Canada and Russia and we can conclude the same results for the countries with similar economic structure and geographical benefits, for example, the Mediterranean and Scandinavian countries may follow the same trend, but regional studies tend to outweigh the positive impacts to a total regional negative consequence.

In particular, Canada is assumed to be benefitting more from tourism sector as a consequence of climate change while Russia benefits from a combination of health-related factors, tourism and agricultural yield. It makes sense to assume positive agricultural outcomes for the two countries as they are of the coldest on earth.

Some countries such as Chile also benefit from agriculture as a consequence however, as it can be seen in Figure 2.3, the risk threatening the health sector of the country is much higher.

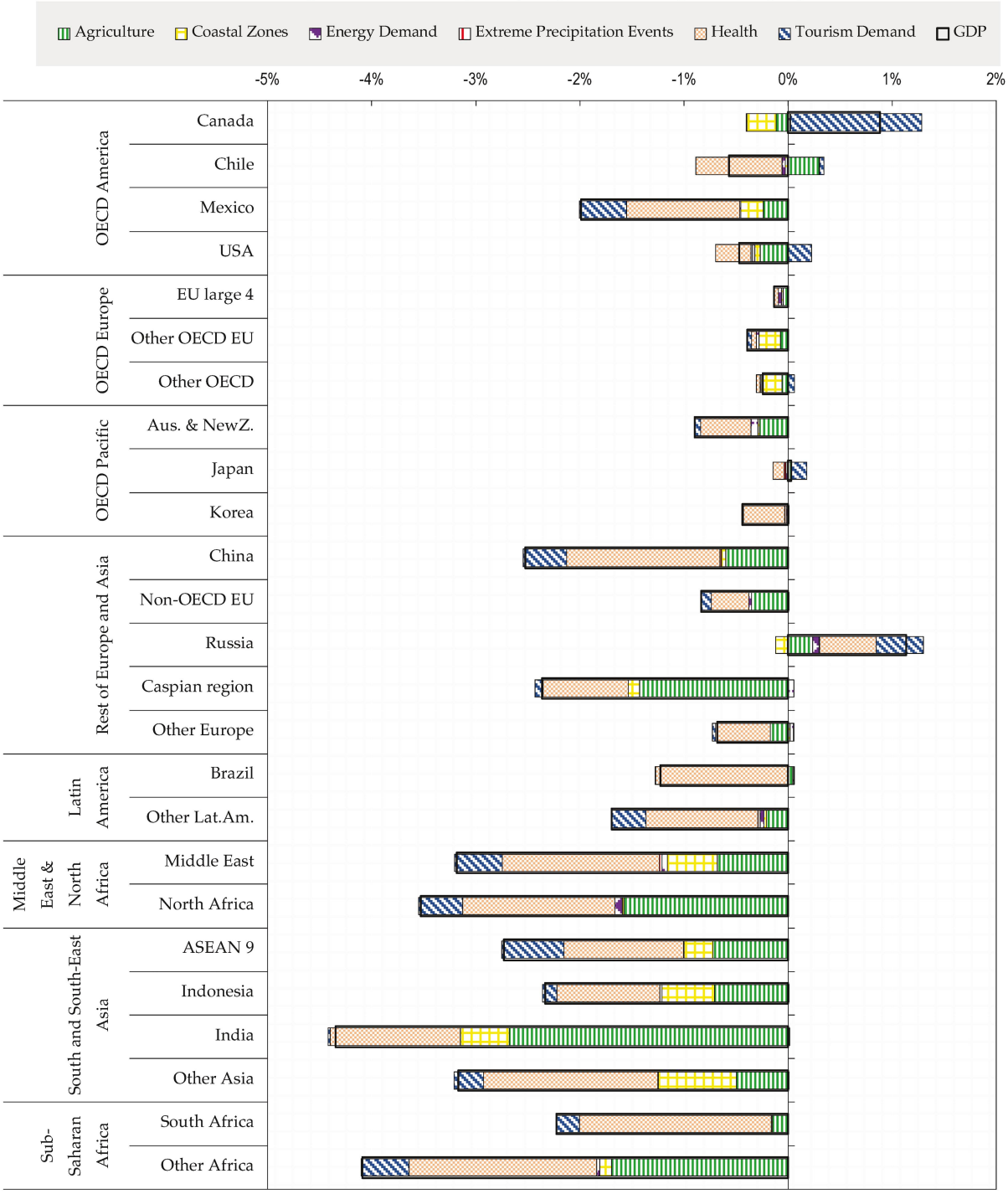
In the US, initially, tourism will have positive impacts while other five of these selected categories tend to show an overall negative outcome since the country's geographical location and demographics suggest that those regions that will benefit from climate change are not the key regions that determine the economic growth of the US.

The modelling also suggests minor net economic benefits from health impacts in some European Union countries, (where relatively small losses in labor productivity are combined with slightly beneficial impacts on health expenditures and disease incidence), so GDP Balance of the four large EU countries (as a group, rather than individually) is not affected at all by the selected climate change impacts assessed.

However, EU's Joint Research Centre (Ciscar et al., 2014) suggests that these slight positive impacts do not necessarily reflect an overall beneficial consequence but rather a competitive advantage in the selected sectors over their main international trade competitors, meaning that these EU countries do not actually see the impact as a growth factor but since the competitors are weakened, they gain the upper hand in many sectors.

In some of the countries, as studied individually it can be seen that an overall interacted impact on GDP is not very substantial and are not necessarily consequential if the only factor of growth and economic welfare is assumed to be GDP growth, however there are countries such as India which are really jeopardized if we only study the individual effects on the sectors of this country. This also suggests that the country needs to respond to the interaction of these effects in a more sophisticated way rather than simply tackling each individual impact.

Figure 2.3 - Damages by region and impact category in 2060

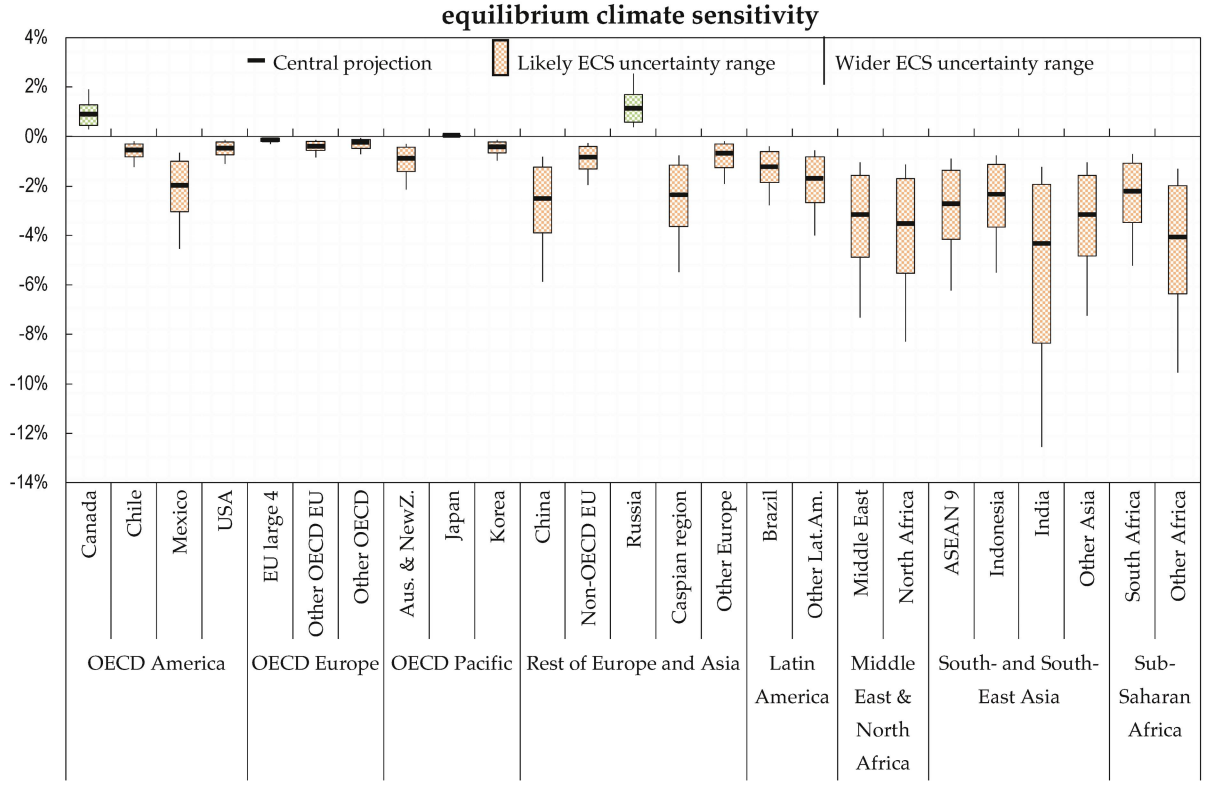


Statistical Source: ENV-Linkage model http://dx.doi.org/10.1787/888933276005

As mentioned in earlier in this chapter, none of these predictions are totally precise and involve degrees of uncertainty due to the environmental climate sensitivity of a region or a particular country. This uncertainty is well demonstrated in Figure 2.4, where the dotted boxes indicate how much regional damages may fluctuate in the likely range

(1.5C-4.5C), while the thin (vertical) black lines highlight that the impacts may be considerably larger (or smaller) when an even wider uncertainty range (1C-6C) is considered. The bolder black lines in the middle show a central projection for different regions.

Figure 2.4 - Uncertainty in regional damages in 2060 due to uncertainty in equilibrium climate sensitivity



Statistical Source: ENV-Linkage model http://dx.doi.org/10.1787/888933276005

As it can be seen in the Figure 2.4, the GDP losses for India and Sub-Saharan Africa are much higher when the climate sensitivity becomes higher and in case of India, with a higher climate sensitivity it can even rise to nearly 12% to 13% loss of income (under the worst-case scenario), the impact is nearly the same of Sub-Saharan Africa, as the values of climate sensitivity grows higher, the loss in GDP could rise up until nearly 10% (again, under the worst case scenario) – these statistics are consistent with the projections of OECD which concludes the range of GDP loss for India from 1.9% to 8.4%, in a 95% confidence interval by 2060 while for Sub-Saharan Africa, the organization estimates that the 95% confidence

interval will range from 2.0% up to 6.4%.

The panel clearly shows that the regional differences in GDP losses in the central projection are relatively small when compared to the uncertainties within a region related to different climate sensitivities. Perhaps equally importantly, the model analysis shows that even at low levels of climate sensitivity there will be significant (although smaller) GDP losses in many countries.

In North America, the highest level of uncertainty with respect to equilibrium climate sensitivity is estimated for Mexico, where on average, the GDP loss by 2060 is calculated 4%, while the range of GDP loss for their northern neighbor, the United States, is much smaller, (0.3% up to 0.9%).

For OECD Europe, where projected impacts are smaller, the likely range is also smaller: 0.1% to 0.4% of GDP by 2060 for the group. For the Asian and Pacific OECD countries, the likely range is larger in the pacific member countries than for the Asian members, which leads to a likely range of 0.1% to 0.5% of GDP by 2060. These projections obviously exclude other uncertainties which can vary for different regional patterns.

2.3 Summary

The regional macroeconomic impacts and their consequences were discussed in details through the chapters. It was also pointed that the projections involve various degrees of uncertainty which are measurable up to a certain extent but exclude uncertainties that arise from different regional patterns of climate sensitivity.

Through the chapter it was indicated that the projections suggest that India and Sub-Saharan Africa will be affected worst and will suffer from the highest GDP decline by 2060, while countries such as Canada, Russia,

the Scandinavian and the Mediterranean are among those who will slightly benefit from these impacts.

From the six economic categories studied through the chapter, in most of the cases, agriculture and health sectors dominate the group in their contribution to negative income growth.

Finally, it was also mentioned that some of the less vulnerable country might very well be able to tackle impacts on different sectors individually while countries at higher risk need to take a more sophisticated approach towards the phenomenon.

Chapter 3

Historical Data Analysis

3.1 Introduction:

In this chapter, we will try to analyze the historic relationship between economic growth and carbon emissions. As it was pointed out in the previous chapters as well, one of the biggest contributors to man-made climate change is the emissions from greenhouse gases as well as the use of CO2. Although, nearly all studies on global climate change suggest that carbon emissions will most likely result into losses in economic growth in the future, it is worth mentioning that since the industrial revolution, carbon emission and the usage of fossil fuels have also contributed to economic growth in general, on the other hand, as world's biggest economies grew in size and in value, more and more carbon was used for production, manufacturing, transportation, public services and many other sectors.

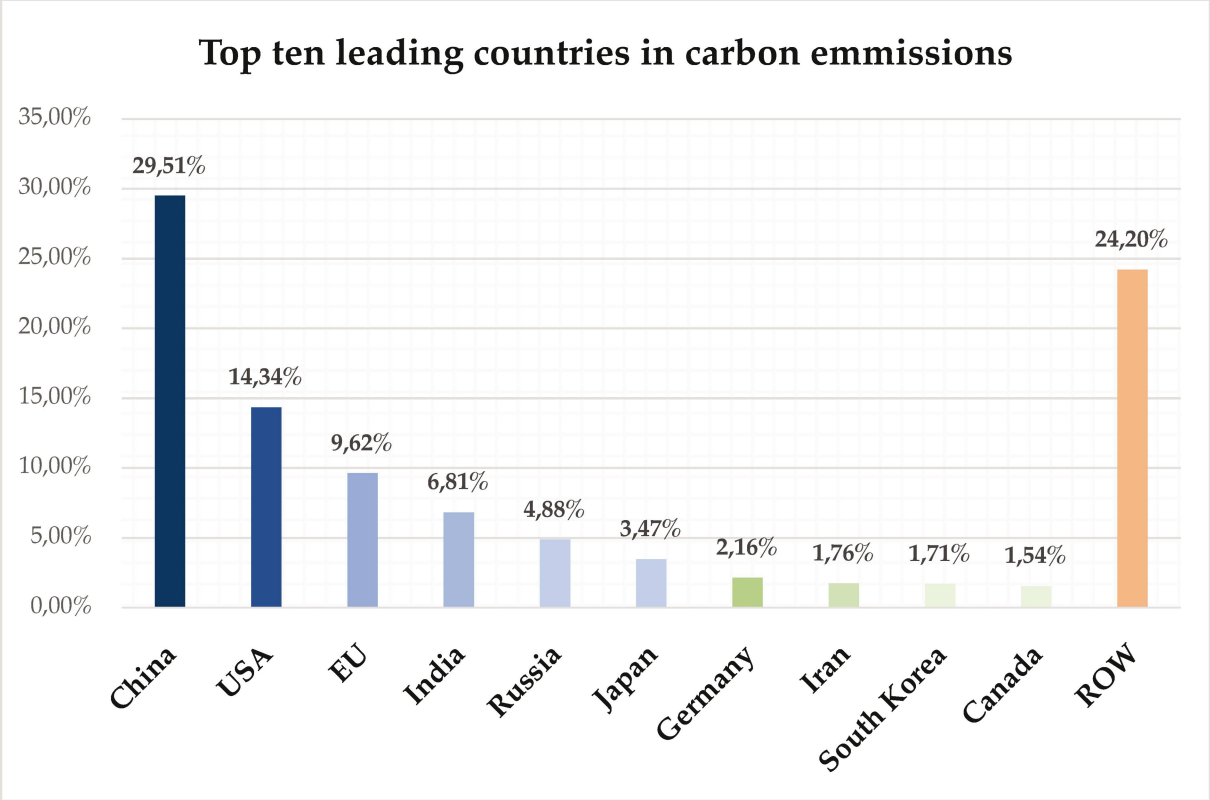
Later in this chapter, most attention will be paid to the future forecast and different estimations of different studies, especially beyond 2060 up to 2100, an attempt will be made to aggregate the findings of some of the most prominent researches on the topic of global climate change and make a conclusion about whether the findings tend to converge to a consensus about the future forecasts or they indicate contradictory results about the future of economic growth, carbon emissions and temperature variations.

3.2 Historical Data Analysis

It was very clearly pointed out in the second chapter of this thesis that some of the most vulnerable countries to the impact of climate change are

some of the poorest or the highly and densely populated countries, but it is important to mention that some the most vulnerable countries, such as India, are also in the list of one of the world's biggest polluters. The bar chart below shows, the world's top ten polluters with respect to carbon emissions.

Bar Chart 3.1 – shows the percentage share carbon emissions by individual countries of the global aggregate



Statistical Source: United Nations Statistics Division

As seen the bar chart above, currently, China leads the world in carbon emissions and emits higher by more than 5 percentage points than the rest of the world – ROW (excluding the other nine leaders).

Among the top five emitters in the world, three are developing countries, among these three, China and India have been observing very high rates of economic growth especially in the past decade, which indicates the necessity to further analyze the relationship of carbon emissions and

economic growth in different regions of the world.

Therefore, in this section, countries have been divided into two main groups:

1. High Income Countries (HICs)
2. Medium and Upper-Medium Countries (MICs)

The division of the countries is in consistency with World Bank data.

Data for 34 countries have been gathered, (17 HICs, 17 MICs) and attempts have been made to analyze the relationship between carbon emissions and economic growth indicators.

3.3 Data:

Data for HICs and MICs have been gathered for a 30-year period (1985 – 2014)

The 17 high income countries are the following:

Australia, Belgium, Canada, Chile, Denmark, Finland, France, Germany, Hong Kong SAR, Japan, Korean Republic (South Korea), Netherlands, New Zealand, Norway, Singapore, United Kingdom and the United States of America.

The 17 middle and upper-middle income countries are the following:

Argentina, Brazil, China, Egypt, India, Indonesia, Iran, Iraq, Lebanon, Malaysia, Mexico, Nigeria, Pakistan, Turkey, Venezuela, Vietnam and Uruguay

Source of the data gathering is the World Bank Data and for every country, data for Total carbon emissions, GDP per capita, Imports in USD values, Exports in USD values, Urban population have been collected for a 30-year time period.

The reason for the country choice is not made arbitrarily but with some observation, as mentioned in previous chapter, that many of the countries in the two groups play some role in the impact of climate change, if not individually then as a key part of the region.

The reason for the time period is simply because data for that period is available for all the countries as opposed to a longer one.

The Panel-Data used for the econometric analysis is balanced. (i.e. observations for all the countries in all periods exist in the data files)

3.4 Model:

The following model will be used to see the effects of economic growth on emissions. The reason why the log-log model is chosen is in order to have an elasticity interpretation of the regressors on the regressand

$$\log(\text{Carbon Emissions}_{i,t}) = \beta_0 + \beta_1 \log(\text{GPD per capita}_{i,t}) + \beta_2 \log(\text{GDP per Capita}_{i,t})^2 + \beta_3 \log(\text{Exports}_{i,t}) + \beta_4 \log(\text{Imports}_{i,t}) + \beta_5 \log(\text{Urban}_{i,t}) + \beta_6 \log(\text{Urban}_{i,t})^2 + u_{i,t}$$

Dependent Variable:

The dependent variable (regressand) is the total carbon emissions in a particular country in a given year in kilo tons as provided by the World Bank Data.

Independent Variable:

Independent variables include, GDP Per Capita in USD dollars (in 2010 value) which is an indicator of economic growth, the reason why a quadratic variable of the GDP per capita in this model is added is that it is very well expected that GDP per capita growth with respect to carbon emissions must follow the Kuznets curve, meaning that as GDP per capita

keeps rising, environmental degradation keeps increasing up to a particular global maximum and further it will keep decreasing, and the reason might very well be the growth of technological innovation in order preserve the environment and provide sufficient energy. The variable, exports, is the total value-added level of exports of an individual country in a particular year and so is the variable import, this will tell us the effect of international trade on carbon emissions, both exports and imports are in the log form. The variable, urban, is the number of people living in a particular country at a particular time in a country, the addition of quadratic term for this variable is justified by argument that after a certain level of population level, the urban areas will tend to decrease their emissions and will, at some point, start to substitute it with more efficient means of energy (for example: Beijing) and finally, $u_{i,t}$ represents the unobserved errors of the model.

Correlation matrices for all the variables in the two groups are provided in Appendix 1

3.5 Method

Since we are dealing with the panel-data, it would have made sense to run a regression that controls for fixed and random effects, and in order to choose from one, we conduct the Hausman test, and in case we reject the null hypothesis against the alternative hypothesis of one model being inconsistent, we continue with the fixed effects model (If we assume fixed effects, we impose time independent effects for each entity that are possibly correlated with the regressors). The results from the regressions of both of these models along with tests for heteroscedasticity, serial correlation (aka autocorrelation), cross-sectional dependence and White's panel correlated standard errors can be seen in the Appendix 1 of this thesis.

However, generally, in the longer period panel-data, especially those that include macroeconomic indicators, the problem of unit roots can be suspected, which are difficult to test for in case we have 34 countries under observation, so in order to address the heterogeneity bias (arising from unmeasured time-invariant differences between the countries) as well as non-stationarity, there exists a slight preference for the first difference estimation.

3.6 Results and Interpretation:

Balanced Panel: n=17, T=30, N=510
Observations used in estimation: 493

Residuals

	Min.	1st Quantile	Median	3rd Quantile	Max.
	-2.30000	-0.02210	0.00671	0.03710	0.48500

Coefficients

	Estimate	Standard Errors	t-value	Pr (>|t|)	
(intercept)	-0.020	0.0114	-1.793	0.0736	*
log (GDP PC)	5.074	2.7817	1.824	0.0687	*
log (GDP PC)²	-0.262	0.1385	-1.894	0.0587	*
log (Exports)	0.037	0.1497	0.252	0.8006	
log (Imports)	0.297	0.1631	1.822	0.0690	*
log (Urban)	9.773	5.9171	1.652	0.0991	*
log (Urban)²	-0.268	0.1862	-1.442	0.1498	

Significance codes: '***' 0.01 '**' 0.05 '*' 0.1
Total Sum of Squares: 8.5924
Residual Sum of Squares: 8.2167
R-Squared: 0.043725
Adj. R-Squared: 0.031919
F-statistic: 3.70364 on 6 and 486 DF, p-value: 0.0013065

Model with Robust Errors

	Estimate	Robust Errors	t-value	Pr (>|t|)	
(intercept)	-0.020	0.0079	-2.569	0.0104	**
log (GDP PC)	5.074	1.7633	2.877	0.0041	***
log (GDP PC)²	-0.262	0.1003	-2.615	0.0091	**
log (Exports)	0.037	0.1223	0.309	0.7572	
log (Imports)	0.297	0.1349	2.203	0.0280	**
log (Urban)	9.773	5.9171	1.652	0.0992	*
log (Urban)²	-0.268	0.1953	-1.375	0.1696	

Table 3.1 – Shows the results of the regression model for the HICs

As expected, the first difference estimates show that the significance of all the variables are weak (excluding exports and urban^2, which are insignificant), the adjusted R-Squared is very low, meaning that very little of the variation in the model is explained by the dependent variables. However, when we use the robust errors, variables (excluding exports and urban^2) become more significant. We can look at the coefficients of [log (GDP PC)] and [log (GDP PC)^2] which show consistency with the assumptions of the Kuznets curve. The negative coefficient in the quadratic variable is the indication of this result.

The coefficient for GDP per capita, at a 99% confidence level, indicates that, all other factors fixed, a 1% rise in that variable has resulted into more than 5% increase in carbon emissions over the course of 30 years on average, (the turning point can be calculated by taking the partial derivative of carbon emissions with respect of GDP per capita) the coefficient for exports, as shown, is statistically insignificant, and both imports and urban population indicate positive effects, meaning 1% rise in each of the variable has increased carbon emissions by 0.2% and 9.7% respectively and the coefficients are significant at a 95% and 90% confidence level.

The Confidence Interval for the estimated model, illustrated in the Table 3.2, shows that, at a 95% confidence level, it can be claimed that the true means for the coefficients lie between these intervals.

Table 3.2 – 95% Confidence Interval for the estimated model

	2.5 %	97.5 %
(intercept)	-0.04288	0.00196
log (GDP PC)	-0.39152	10.5401
log (GDP PC)^2	-0.53461	0.00977
log (Exports)	-0.25636	0.33202
log (Imports)	-0.02327	0.61799
log (Urban)	-1.84971	21.40311
log (Urban)^2	-0.63469	0.097310

The model was tested for heteroscedasticity and serial correlation, (see Appendix 1), evidence of both which were not found.

Using the same model, with the same specifications, a regression using the data for MICs was ran, the results are illustrated in Table 3.3

Table 3.3 – Shows the results of the regression model for the MICs

Balanced Panel: n=17, T=30, N=510
Observations used in estimation: 493

Residuals

Min.	1st Quantile	Median	3rd Quantile	Max.	
-0.559000	-0.035100	0.000418	0.041200	0.530000	
Coefficients	:				
	Estimate	Standard Errors	t-value	Pr(>|t|)	
(intercept)	0.0234	0.0113	2.0721	0.0387	*
log (GDP PC)	0.5976	0.4453	1.3421	0.1801	
log (GDP PC)²	-0.0261	0.0263	-0.9944	0.3205	
log (Exports)	-0.0094	0.0229	-0.4139	0.6791	
log (Imports)	0.0138	0.0262	0.5293	0.5968	
log (Urban)	1.0396	2.0489	0.5074	0.6120	
log (Urban)²	-0.0178	0.0580	-0.3082	0.7580	

Significance codes: '***' 0.01 '**' 0.05 '*' 0.1

Total Sum of Squares: 4.6977
Residual Sum of Squares: 4.5889
R-Squared: 0.023158
Adj. R-Squared: 0.011098
F-statistic: 1.92028 on 6 and 486 DF, p-value: 0.075856

Model with Robust Errors

	Estimate	Robust Errors	t-value	Pr(>|t|)	
(intercept)	0.0234	0.0104	2.2518	0.0247	**
log (GDP PC)	0.5976	0.2829	2.1124	0.0351	**
log (GDP PC)²	-0.0261	0.0149	-1.7493	0.0808	*
log (Exports)	-0.0094	0.0137	-0.6916	0.4895	
log (Imports)	0.0138	0.0288	0.4823	0.6298	
log (Urban)	1.0396	1.5908	0.6535	0.5137	
log (Urban)²	-0.0178	0.0391	-0.4575	0.6474	

Although initially the first differenced model estimates all the coefficients to be statistically insignificant indicating a weak relationship between economic factors in general with carbon emissions in the MICs, once the robust errors are added, the coefficients of [log (GDP PC)] and [log (GDP PC)^2] become significant with a P-Value < 0.05.

It can be seen that the signs in the coefficients do not differ from the estimates for the HICs, but the percentage effect is lower than the one calculated for HICs. To be precise, the coefficient of GDP Per Capita shows that 1% increase in the GDP Per capita increases carbon emissions by 0.59% in the MICs, the emissions reach up to a global maximum from which point, it starts decreasing as GDP Per capita increases.

Table 3.4 – 95% Confidence Interval for the estimated model

	2.5 %	97.5 %
(intercept)	0.00121	0.04572
log (GDP PC)	-0.27732	1.47268
log (GDP PC)^2	-0.07792	0.02555
log (Exports)	-0.05454	0.03556
log (Imports)	-0.03769	0.06548
log (Urban)	-2.98622	5.06557
log (Urban)^2	-0.13198	0.09619

Conclusion

An econometric analysis was done this section, the methodology and data gathering process was explained and further, the dependent variable, carbon emissions was regressed on economic indicators namely, GDP per capita, exports, imports and urban population to see their effects on carbon emissions.

On a 99% confidence level, for high income countries the results indicated that carbon emissions rise up to a certain level of GDP per capita growth which was followed by a decrease, as GDP per capita increased further which confirmed the expectations.

Chapter 4

Policy Consequences

4.1 Introduction:

In this chapter, more discussion about the cost of climate change beyond 2060 will be made. There are two main choices basically left to policy makers, the first one is to start taking preventive and precautionary actions as soon as possible, which will come with certain present costs but also prevent future heavier losses, the second approach is to keep "business as usual" and in the future, individually respond to the challenges faced.

For the beginning of this chapter, the effect of climate change on aggregate output and inflation will be briefly discussed, the consequences of policy inaction will be mentioned and later, it will be investigated whether there are actual, implementable policies to bring the future damages to its minimum starting right now.

4.2 What Happens to Aggregate Output and Inflation?

As it was pointed out in Chapter 2, the most likely impact of temperature-increase and global warming indicates a negative outcome for the majority of the world economy up until year 2060.

Although there are some countries, which are affected positively by the climate change (e.g. Canada, Russia etc.) There is very less evidence to conclude that this impact will continue to remain positive beyond 2060 until 2100.

In the studies conducted by Dietz and Stern (2014), Weitzman (2011) and Nordhaus (2013), although with different estimations, the consensus reached is that global warming, beyond 2060, in the business as usual

scenario (i.e. inaction), will most likely affect economic growth by damaging capital stocks, lost productivity and human security threats besides the two leading contributors which are agricultural and health sectors.

While the initial economic response to recover this damage may be positive for GDP (when it is possible to do so), once it is recognized that such events are a permanent feature of the environment, the world economy faces an extreme challenge. Many will find that it is not worth replacing capital stock unless measures can be taken to prevent future damage, or there is an opportunity to move the business to safer ground. At best, this could involve a short period of disruption as businesses relocate; at worst, a permanent loss of capital stock and output. As the temperatures continue to climb, the damage will become increasingly permanent. (Schroders 2014)

By using a simplified production function graph, as in Figure 4.1, we can explain how damages to the world output will occur. First, under the assumptions that as temperatures keep rising, less and less capital becomes available for the labor force, and under the heat stress, the labor force can be assumed to become less productive. In general, this will cause the overall world production function to shift downwards (i.e. given the of available capital stock and lesser labor productivity). This will translate into lesser output produced by the labor although the labor supplied will be the same. This downward shift is illustrated in Figure 4.1 as the downward shift in the production function causes the output level to fall from Y_1 to Y_2 although L remains the same. At the same time, since output is descried simply here as a function of both labor and capital, the downward shift is also induced by the given level of capital, therefore K_1 and K_2 show different levels of capital stocks ($K_1 > K_2$)

Meanwhile, as illustrated in Figure 4.2, the effects can also be translated

as supply shocks, meaning that at any given level of demand, the supply curve will shift downwards from S_1 to S_2, resulting in lesser supplied output at a higher price. The distance from Y_1 to Y_2 is the level of output decrease while the distance from P_1 to P_2 described the increase in overall price level in the economy.

Figure 4.1

Global Production effects

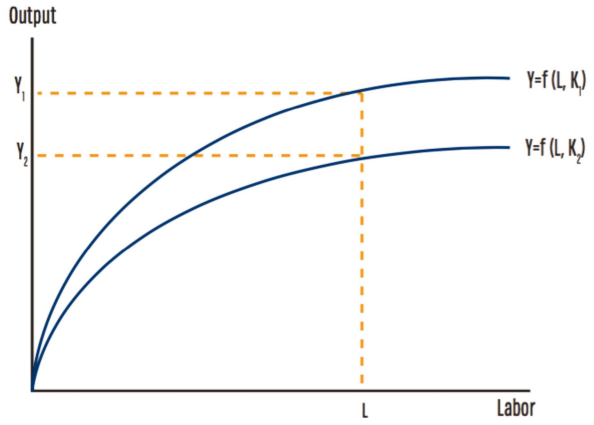
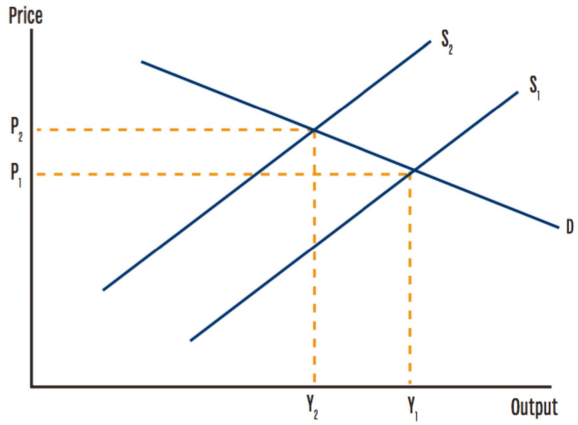


Figure 4.2

Supply and Demand Effects



It needs to be mentioned that these simplified models are based on a *ceteris paribus* effect (i.e. keeping all others fixed). Here, the population growth over the century has not been taken into account, which might have its effects either way.

There exists a possibility of taking preventive action, meaning that in order to reduce or possibly eliminate future losses, certain costs need to be undertaken, in other words, a temporary economic transition from consumption to investment. Preventive action may either be precautionary such as enormous investments in green energy and huge cuts in carbon emissions or defensive, for example building strong flood defenses. Both situations are costly. As much as one may argue that these present costs reduce future losses by significant amounts, cutting from today's consumption for the future, in its entirety acts like tax-increases,

to put it another way, it has proved to be politically unpopular in some of the major economies in the world such as the United States to the extent that the administration of the country very recently announced that it will cease all the implementation of the non-binding Paris accord.

According to Mendelsohn (2013): "the biggest threat climate change poses to economic growth is from immediate, aggressive and inefficient mitigation policies. The process of adaptation and mitigation will require a temporary shift from consumption to investment, with the argument being that the transitional costs are small relative to the cost of inaction."

Stern (2006) estimates the costs of mitigation to be in the region of 1% of global GDP per annum by 2050.

However, it can be argued that the costs will most likely follow a non-linear trend, as the costs of mitigation rises, it becomes much more difficult for the governments to raise necessary capital to cope with the effects.

4.3 Inflationary Effects

The simplified supply-demand model in Figure 4.2 not only shows a decrease of output but also an increase in the overall price-level in the economy as a consequence of shortages that might arise due to severe environmental effects.

The shortages most likely arise from agricultural deficiencies. Although some might argue that to some extent, these effects might be offset by positive agricultural gains in other regions, but it certainly will not continue to be so until the end of the century an at the same time, regions that are positively affected, even in the short term, may not have the capacity to balance the shortages for the whole globe.

Furthermore, as global temperatures rise, demand for energy will rise

since cooling and heating will be demanded more due to much hotter summers and harsher winters. It will soon be evident that the current energy output of the world is in no way sufficient to meet the demands. Both the rise of demand, and a shrink in the energy supply - as a result of current energy stations being compromised - will have inflationary effects

Given that energy forms the basis of most of the world's production, the secondary effects of higher energy prices on inflation will be felt throughout the global economy. Conversely, depending on the pace of change, the greater prominence of renewable energy could limit the cost of energy increases going forward.

Finally, as extreme events in the environment are associated with higher probabilities, the cost of insurance becomes higher, premiums start to rise making it harder, especially for the small business to efficiently operate. The rise in insurance premiums will also rise the overall prices in the markets, since businesses will have to increase the prices for their goods and services.

4.4 Predictions for the Century

The three main studies mentioned earlier in this chapter quantify the losses as a result of temperature increase in a so-called "damage function". The function, by definitions measures the fraction of output decrease given some level of temperature rise against the hypothesis that there is not warming.

The consensus however on the marginal effects of temperature rise on the negative output growth has not been reached. As it can be seen in the Table 4.1 follow by the Figure 4.3, the estimates vary significantly from one another.

In this section, a brief discussion about each climate damage function below will be provided, focusing on the 4°C mark given that the World Bank estimates there is a 40% chance of exceeding this level by 2100, assuming emissions follow a "business-as usual pathway".

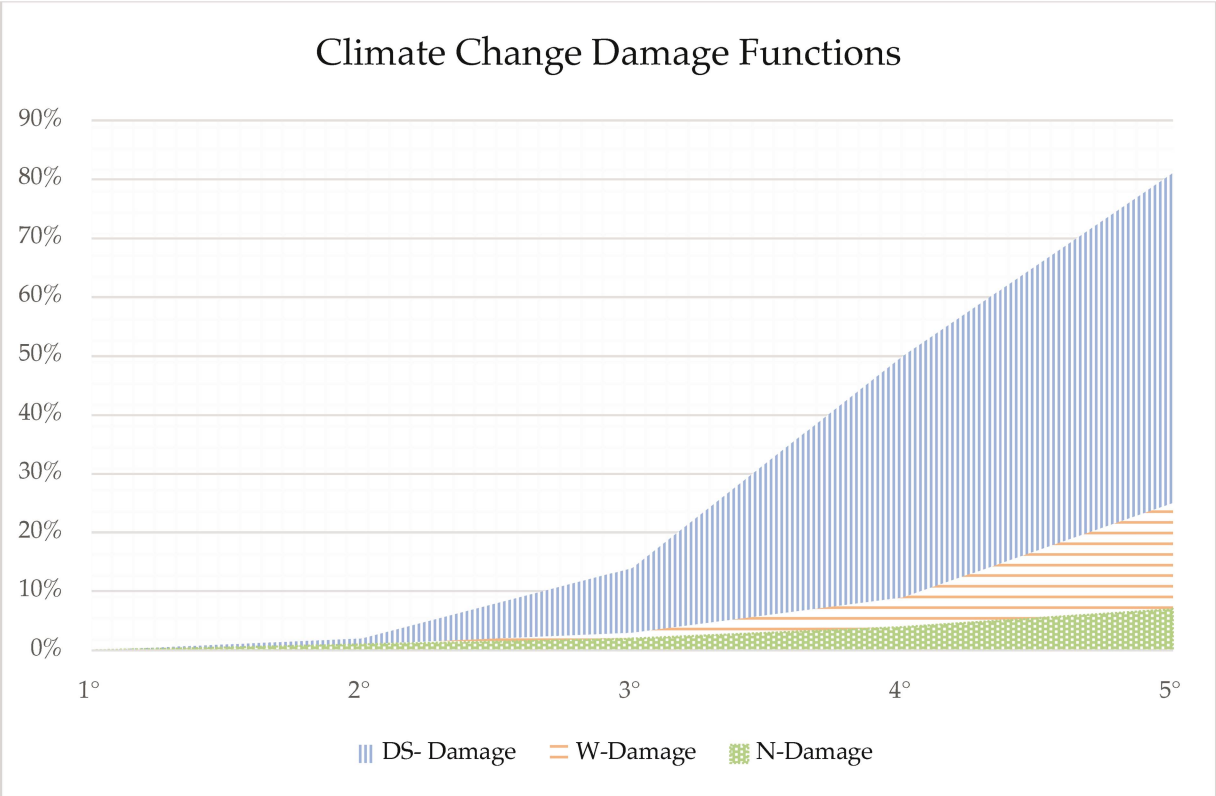
Table 4.1 – Climate Change Damage Functions

Estimates of climate damage at varying degrees of warming. Climate damage is defined as the fractional loss in annual economic output at a given level of warming compared to output in the same economy with no warming.

	Climate Change		
Warming	DS- Damage	W-Damage	N-Damage
1°	0%	0%	0%
2°	2%	1%	1%
3°	14%	3%	2%
4°	50%	9%	4%
5°	81%	25%	7%

Figure 4.3 – Climate Change Damage Functions

Climate damage forecasts at a given level of warming based on estimates by Dietz and Stern (2014), Weitzman (2012) and Nordhaus (2013).



Nordhaus 2013 or the "N-Damage" function, as it can be seen both in Figure 4.3 and in Table 4.1 is the least concerning one, showing a normal trend for GDP decrease as temperature rises to different values.

Under this function, damages arising from climate change will be progressive and no tipping point is reached and the world's population has the greatest amount of time to offset any negative effects of global warming. It can be seen that by the year in which the world is 4°C warmer, annual economic output will be just 4% lower than a base case with no warming. The baseline case in Nordhaus's study is for warming of around 3.8% by 2100.

With such a damage function, Nordhaus concludes that the economic

impact of climate change for the next two decades will likely be very small, however, once the threshold of 4-degree Celsius is reached, significant effects can be noticed. But, according to Nordhaus, given that 4-degrees Celsius rise in the temperature from the baseline is something that will be reached after many decades, the economic impacts generally will be extremely difficult to distinguish.

Next, the W-damage function named after Weitzman, is the moderate predictions of economic loss due to climate change during the century. This study estimates that by the time 4°C of warming is reached, 9% of annual economic output will be lost relative to the base with no warming effect. Under this scenario, those industries that are largely predisposed to climate change risk globally are likely to be affected, for example insurance, agriculture and forestry. However, Pearce et al (1996) believes that only a fraction of the market economy is vulnerable to global warming, namely agriculture, coastal resources, energy, forestry, tourism, and water. These sectors contribute just 5% of global GDP to which their share is expected to shrink overtime (Mendelsohn, 2013)

Finally, the DS-Damage function, named after Dietz-Stern (2014), predicts the most extreme scenario, which estimates that when global temperature rises by 4-degrees Celsius from the baseline average, the global economy will decrease with respect to global output by 50% compared to the scenario where the is no warming.

To put this into perspective, Dietz and Stern estimate warming of approximately 3.5°C by 2100. If we take a stricter approach however, using the same assumptions as the W-damages function above but assuming 4°C is reached in 2080, the base case 3% annual economic growth rate falls to just 1.9% a year. Dietz and Stern predict that a tipping point will be reached at 2-3 degrees Celsius, at which point, insufficient policy actions will lead to extreme economic loss.

On the other hand, the Intergovernmental Panel on Climate Change in their analysis conclude that a 2-degrees Celsius temperature rise is not likely to happen in the upcoming two decades but conclude that losses show an acceleration once the 2-degree limit is reached.

However, this needs to be pointed out that global warming happens over time, which is an irreversible process, meaning that action needs to be taken now or else, reactions will not be sufficient in the future. This argument is made by the World Bank in their study "Turn Down the Heat". The study concludes that a warming of 1.5-degrees Celsius above the pre-industrial average is unavoidable, but with current level of carbon emissions, in case preventive action is not taken starting right now, a (2-4 degrees Celsius) rise will be certain by 2050, and 2100 respectively which certainly will decrease overall global output under any circumstance.

The difference in the estimation of DS-Damage and W-Damage functions mostly rises from using different discount rates for future forecast. Dietz and Stern use a slightly higher than expected future discount rate to evaluate the losses in the GDP growth as a consequence of temperature increase.

4.5 Summary

This chapter concentrated on two economic indicators which will likely be affected by the global warming, aggregate output and inflation. While it was argued and shown that aggregate output will decrease, the general price level in the economy (i.e. inflation) rise due to shortages.

Further, more attention was paid to different predictions for the century by the most prominent studies of climate change and its effects economic growth, although estimates under uncertainty were different, all studies agreed that most likely a 4-degrees Celsius rise in the temperature, above the pre-industrial average, will be likely with current level of emissions

and it will certainly decrease the overall output by the end of the century.

The impacts of policy action were also discussed briefly and it was pointed that undertaking the costs presently is burdensome to many nations and this fact contributes to delayed policy action which can eventually prove to be disastrous, since delayed action will not be sufficient.

Chapter 5

Climate Finance and Current Issues

5.1 Introduction:

This chapter will focus on the current obligations of the countries in order to keep following the agreements made on the reduction of carbon emissions, as a part of the effort to keep the average level of carbon concentration in the atmosphere to the desired level and by doing so, attempt to prevent future temperature rise to the levels where the disasters become unavoidable.

5.2 Fiscal Policy for Mitigation

The Intended Nationally Determined Contributions (INDCs) are the quantitative emissions targets set by countries around the world to share the burden of the impacts of climate change. These targets are set nationally, policy making and practice is voluntary to many extents. In the Paris Agreement (aka The Paris Climate Accord) this approach was described as significantly important as well as practical.

The approach in many nations is to direct policy in the manner where both carbon emissions are decreased as a consequence and reliance on green and renewable is encouraged.

The table below shows the world biggest carbon emitters and their pledges to reduce their emissions by 2025 and 2030 by some percentage points and thus, reduce their global share of greenhouse gas emissions eventually.

Table 5.1 – Submitted INDCs – Largest Emitting Countries

Country	Mitigation Pledge Made at National Level	Current Share
China	Lower CO2 intensity of GDP to 60-65%	29,51
USA	Reduce GHGs to 26-28% below 2005 levels by 2025	14,54
EU	Reduce GHGSs 40% below 1990 levels	9,62
India	Lower GHGs intensity of GDP to 30-35% below 2005 level by 2030	6,81
Russia	Reduce GHGs 25-30% below 1990 levels by 2030	4,88
Japan	Reduce GHGs 20-30% below 2005 levels by 2030	3,47
Korea	Reduce GHGs 37% below BAU in 2030	1,71
Canada	Reduce GHGs 30% below 2005 levels by 2030	1,54
Indonesia	Reduce GHGs 37% below BAU in 2030	1,39
Brazil	Reduce GHGs 37% below 2005 in 2030	1,35
Mexico	Reduce GHGs 37% below BAU in 2030	1,31
Australia	Reduce GHGs 26-28% below 2005 levels by 2030	1,24

Source: UNFCCC (2016)

The recommendation in the Paris agreement is that these targets can be met only by explicitly taxing carbon itself, however there is no mention of initially or at a later date, subsidizing investments in the renewable energy perhaps because such a policy will tend to distort prices in an unexpected manner.

(In case of the United States, the current share and the GHG reduction commitment might differ as a consequence of the decisions made by the current administration of the country with respect to the Paris accord)

In the Paris Accord, as a part of policy making decisions, countries are urged to set carbon prices so that the level of carbon consumptions are indirectly limited, and dependence is shift towards nuclear energy and solar energy.

The strategy is quite direct and explicit, countries normally price (tax) carbon and carbon related consumptions. Such approach at least for the short term has proved to be positive and has resulted to some extent, to the decrease of carbon emissions, fuel demands, transportation fuel,

electricity generated by the fuel products and so on and at the same time, reliance on nuclear, solar and wind produced energy has increased.

The two positive aspects of this approach are that, first it is actually environmentally effective and second, investment in the renewable and green energy has fiscally been proved positive, many countries have used this tool as a fiscal stimulus as well, which has not only led to technological progress but also in creation of new job sectors.

The policy that has not been proved empirically beneficial and very less effective to reduce carbon emissions is carbon regulations, (i.e. setting emission rates, setting renewable standards and energy efficiency standards). The reason is that this policy has not generated any revenue while the first one has had a positive economic effect overall.

The regulatory policies have considerably been useless in the developing country in contrast to carbon taxing because most of the developing countries have not been able to implement the regulations properly and in some cases, the bureaucracy has led to corrupt processes.

Lastly, it is important to mention that policies regarding the reduction of carbon emissions are very new and therefore, a good time-series effects of them cannot be built yet, and most of the consequence of these policies will be observed in the years ahead.

5.3 Climate Finance

Climate finance is about financing the mitigation and adaptation strategies and policies. The challenge to climate financing right now is to mobilize 100 billion USD by 2020 from developed to developing countries. There are concerns on the spending side about the balance between mitigation and adaptation (currently most is on the former), allocating funding across countries and projects accounting for efficiency and equity,

and avoiding paying for projects that would have gone ahead without funding.

The Green Climate Fund (GCF) was established in 2014 which has so far raised more than 10 Billion USD from 35 different developed countries to mobilize it to the developing countries for the implementation of mitigation and adaptation policies.

As pricing carbon was mentioned earlier, the above-mentioned fund estimated that putting a 30 USD price on per ton of CO2 in the developed countries would have raised an estimated 25 billion USD in 2014.

And lastly, a good source for climate finance can be charging the international aviation and maritime emissions. In case the 30 USD price on per ton CO2, again, 25 billion USD could have been raised.

However, it is worth knowing that international coordination in this matter is really weak and the problem of free-ride exists as well, therefore, some of the key contributors have also shown reluctance to implement this price on carbon sense an aggregate raise in funding sometimes translates do high domestic costs. This relates to the issue of unpopularity of undertaking the present costs as mentioned in the Chapter 3.

5.4 Role of the International Monetary Fund (IMF)

The IMF is expected to be playing the role of a technical assistant with regards to climate financing, mitigation and adaptation policies as well as carbon price strategy.

Besides providing practical guidance on the design of fiscal policy for climate mitigation and finance, the IMF has developed spreadsheet tools to quantify, for more than 150 countries, the efficient level of energy taxes to address climate and other environmental costs, and the carbon, fiscal, economic, and broader environmental benefits of price reform. Ongoing work is quantifying carbon pricing consistent with country-level mitigation pledges and the trade-offs across a broad range of fiscal and regulatory mitigation instruments.

Working with other international organizations, the IMF promotes dialogue on these issues among policymakers. The IMF regularly provides technical assistance to member countries on energy pricing reform, and carbon taxation is a natural extension. (IMF 2015)

On climate finance, the IMF emphasizes the attractiveness of carbon pricing instruments. Applied to developing countries these instruments attract private flows and applying them to fuels used in international aviation and maritime transport can raise significant public sources.

Conclusion

This thesis focused on the impacts of climate change on the global economy. Firstly, the impacts were explained at an aggregate level and further, regions were separated and focused on individually.

Furthermore, economic sectors that are more likely to face severe consequences were categorized and paid attention to separately. The likelihood that some regions in the short-term will be affected positively was also discussed and it was pointed that the share of such regions are relatively small and there is lesser evidence to show that even these regions, will continue to be the winners after all.

Over all, short term benefits from climate change cannot offset the long-term impacts of climate change unless preventive action is taken as soon as possible. Countries have pledged themselves to the reduction of carbon emissions in order to contribute to the mitigation process, however, under huge uncertainty, decision making becomes harder thus, posing the question that at what stage, which policies and strategies will very likely be optimal.

In general, a consensus exists about the negative effects of climate change until the end of the century, however the estimates provided differ from one study to another.

Understanding the impacts of climate change in the future is quite a difficult exercise, let alone quantifying it precisely, but there are no evidence suggesting that not taking action at all, will not have severe disastrous consequences. It may be costly today, for the countries, to commit to certain level of emissions, but it is necessary if minimum future losses are desired.

References

1- *World Bank Data – www.data.worldbank.org*
2- *IMF – www.imf.org*
3- *UN Data – www.data.un.org*
4- *Jeffery M.Wooldrige – 2012 (Introductory Econometrics)*
5- *An Introduction to R*
6- *Notes on R: A Programming Environment for Data Analysis and Graphics Version 3.4.1 (2017-04-30)*
7- *Richard S.J. Tol – The Economic Effects of Climate Change – Journal of Economic Perspective – Spring 2009*
8- *Oliver Deschenes and Michael Greenstone – The Economic Impact of Climate Change – Evidence from Agricultural output and Random Fluctuations in Weather*
9- *After Paris: Macroeconomic and Financial Implications of Climate Change - Mai Farid, Michael Keen, Michael Papaioannou, Ian Parry, Catherine Pattillo, Anna Ter-Martirosyan, and others – January 2016*
10- *Weitzman, Martin L., 1974. "Prices versus Quantities." The Review of Economic Studies*
11- *Verisk Maplecroft, 2015, Climate Change Exposure Index. Bath, United Kingdom*
12- *Burke, M, S. Hsiang, and E. Miguel, 2015. "Global Non-linear Effect of Temperature on Economic Production."*
13- *OECD – Economics of Climate change - 2014*
14- *Dellink, R. et al. (2014), "Consequences of Climate Change Damages for Economic Growth: A Dynamic Quantitative Assessment", OECD Economics Department Working Papers, No. 1135, OECD Publishing, Paris,*
15- *IPCC (2014a), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects, Contribution of Working Group II*
16- *IPCC (2014b): Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III*
17- *Ciscar. J.C. et al. (2014), "Climate Impacts in Europe. The JRC PESETA II Project", JRC Scientific and Policy Reports, No. EUR 26586EN, Luxembourg: Publications Office of the European Union.*
18- *Dietz, S. and N. Stern (2015), "Endogenous growth, convexity of damages and climate risk: how Nordhaus' framework supports deep cuts in carbon emissions", The Economic Journal, forthcoming; available as Grantham Research Institute on Climate Change and the Environment Working Paper 159, London.*
19- *Nordhaus, W.D. (2012), "Integrated Economic and Climate Modeling", in: P. Dixon and D. Jorgenson (eds.), Handbook of Computable General Equilibrium Modeling, Elsevier.*
20- *Nordhaus, W.D. (2007), A question of balance, Yale University Press, New Haven, United States.*
21- *OECD (2014a), "Climate Change, Water and Agriculture: Towards Resilient Systems", OECD Studies on*
22- *Water, OECD Publishing, Paris, OECD (2014b), The Cost of Air Pollution: Health Impacts of Road Transport, OECD Publishing, Paris*
23- *OECD (2014c), "Perspectives on Global Development 2016: New Challenges and Opportunities for International Migration in a Shifting World", Concept Note for Expert Meeting on 24-25 February 2015 in Paris.*
24- *OECD (2012a), OECD Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris,*
25- *Pindyck, R.S. (2012), "Uncertain outcomes and climate change policy", Journal of Environmental Economics and Management, Vol. 63, pp. 289-303.*
26- *Stern, N. (2013), "The structure of economic modelling of the potential impacts of climate change: Grafting gross underestimation of risk onto already narrow science models", Journal of Economic Literature, Vol. 51(3), pp. 838-859.*
27- *Stern, N. (2007), Stern Review: The Economics of Climate Change, Cambridge: CUP.*
28- *Weitzman, M.L. (2012), "GHG targets as insurance against catastrophic climate damages", Journal of Public Economic Theory, Vol. 14(2), pp. 221-244.*
29- *United Nations (2013), World Population Prospects: The 2012 Revision, UN Department of Economic and*
30- *Social Affairs.*
31- *Nelson, G.C. et al. (2014), "Climate change effects on agriculture: Economic responses to biophysical shocks", Proceedings of the National Academy of Sciences, Vol. 111(9), 3274-79.*
32- *Nordhaus, W.D. (2013), The climate casino: Risk, uncertainty, and economics for a warming world, Yale University Press, New Haven.*
33- *Bosello, F., F. Eboli and R. Pierfederici (2012), "Assessing the Economic Impacts of Climate Change. An Updated CGE Point of View", FEEM Working Paper, No. 2.*

Appendix 1

Part 1 - Explaining the Variables in the DICE Model

Variables:

For a detailed understanding of the model, the economic variables in the DICE model will be illustrated here in order to introduce both the baseline model and the economic variables of the DICE model is to eventually make an overall projection on how the GDP growth rate will be affected once we have taken into account the underlying explanatory variables that effect the overall output produced with current economic and environmental policies.

It also needs to be mentioned that many classic macroeconomic models make projections for some years ahead, while in order to make predictions about the aggregate effect of climate change on economy, we need to deal with a century long time gap, and therefore, the evidence for that is rather thin. (Noardhaus 1994)

To begin with, the DICE model describes the outcomes which are directly influenced by consumptions, investment and abatement, we firstly assume that consumption is that of just a single commodity and that commodity includes all types of market and non-market goods and services, furthermore, the output is taken simply from data gathered from different regions (USA, China, India, EU and so on) and the aggregated as a whole.

Each region is endowed with an initial stock of capital and labor and an initial and region-specific level of technology. Population growth and technological change are region-specific and exogenous, while capital accumulation is determined by optimizing the flow of consumption over time for each region. Regional outputs and capital stocks are aggregated using purchasing power parity (PPP) exchange rates (IPCC Fourth Assessment, Mitigation 2007 and Nordhaus 2007a).

Next, the equations for the different economic variables in the DICE- 2013R model is described. The first set of equations determines the evolution of world output over time. Population and the labor force are exogenous. These are simplified to be logistic-

type equations of the form $L(t) = L(t-1) * [1 + g_L(t)]$ where

$g_L(t) = \frac{g_L(t-1)}{(1+\delta_L)}$ The initial population in 2010 is given, and the growth rate declines so that total world population approaches a limit of 10.5 billion in 2100. The initial growth rate of population, $g_L(2015)$, of 13.4% per period (5 years) is set so that population equals the UN projection for 2050. These numbers have been revised upward in line with the most recent UN projections and are about 20 percent higher than the 2007 DICE model estimates.

Output is produced with a Cobb-Douglas production function in capital, labor, and energy. Energy takes the form of either carbon-based fuels (such as coal) or non-carbon-based technologies (such as solar or geothermal energy or nuclear power).

Technological change takes two forms: economy-wide technological change and carbon-saving technological change. The level of total factor productivity (TFP), A(t) is a logistic equation similar to that of population. It takes the form:

$$A(t) = A(t-1) * [g_A(t)] \text{ where } g_A(t) = \frac{g_A(t-1)}{(1+\delta_A)}$$

In this specification, TFP growth declines over time. In the current specification, A(2010) is set to calibrate the model to gross world product in 2010; $g_A(2015) = 7.9$ % per five years; and $\delta_A = 0.6\%$ per five years. This specification leads to growth in consumption per capita of 1.9% per year from 2010 to 2100 and 0.9% per year from 2100 to 2200.

Carbon-saving technological change is modeled as reducing the ratio of CO_2 emissions to output (described below). Carbon fuels are limited in supply, with a total limit of 6000 billion tons of carbon content. In the current version, the carbon constraint is not binding in the base case. Substitution from carbon to non-carbon fuels takes place over time as carbon-based fuels become more expensive, either because of resource exhaustion or because policies are taken to limit carbon emissions.

The underlying population and output estimates are aggregated up from a twelve-region model. Outputs are measured in purchasing power parity (PPP) exchange rates using the IMF estimates (Nordhaus 2007). Total output for each region is projected using a partial convergence model, and the outputs are then aggregated to the world total. The regional and global production functions are assumed to be constant-

returns-to-scale Cobb-Douglas production functions in capital, labor, and technological change. Global output is shown in Equation (4):

(4) $Q(t) = [(1 - \lambda(t)] * A(t) * K(t)^{\gamma} * L(t)^{1-\gamma} * [1 + \Omega(t)]$

In this specification, Q(t) is output net of damages and abatement, A(t) is total factor productivity, and K(t) is capital stock and services. The additional variables in the production function are $\lambda(t)$ and, $\Omega(t)$ which represent climate damages and abatement costs, shown in Equations (5) and (6).

(5) $\Omega(t) = \psi_1 * T_{AT}(t) + \psi_1 * [T_{AT}(t)]^2$

Equation (5) involves the economic damages or impacts of climate change, which is the trickiest issue in climate-change economics. These estimates are indispensable for making sensible decisions about the appropriate balance between costly emissions reductions and climate damages. However, providing reliable estimates of the damages from climate change over the long run has proven extremely difficult.

The damage function in (5) has been greatly simplified from earlier DICE/RICE versions. Earlier versions relied on detailed sectoral estimates from Nordhaus and Boyer (2000). However, further work indicated that those estimates were increasingly outdated and unreliable.

The 2013 model instead uses a highly-simplified damage function that relies on current estimates of the damage function. More precisely, DICE-2013R uses estimates of monetized damages from the Tol (2009) survey as the starting point. However, current studies generally omit several important factors (the economic value of losses from biodiversity, ocean acidification, and political reactions), extreme events (sea-level rise, changes in ocean circulation, and accelerated climate change), impacts that are inherently difficult to model (catastrophic events and very long-term warming), and uncertainty (of virtually all components from economic growth to damages). an adjustment of 25 percent of the monetized damages to reflect these non-monetized impacts has been added. While this is consistent with the estimates from other studies (see Hope 2011, Anthoff and Tol 2010, and FUND 2013), it is recognized that this is largely a judgmental adjustment. The current version assumes that damages are a quadratic function of temperature change and does not include sharp thresholds or tipping points.

Figure 2 shows the results of the Tol (2009) survey on damages, the IPCC assessment from the Third and Fourth Assessment Reports, and the assumption in the DICE-2013R model as a function of global mean temperature increase.

An important warning about the functional form in equation (5) when using for large temperature increases is that damage function has been calibrated for damage estimates in the range of 0 to 3 °C. In reality, estimates of damage functions are virtually non-existent for temperature increases above 3 °C. Note also that the functional form in (5), which puts the damage ratio in the denominator, is designed to ensure that damages do not exceed 100% of output, and this limits the usefulness of this approach for catastrophic climate change. The damage function needs to be examined carefully or re-specified in cases of higher warming or catastrophic damages.

The abatement cost function in equation (6) shows the determinants of $\lambda(t)$, which is the ratio of abatement cost to output.

$$(6)\ \lambda(t) = \theta_1(t) * \mu(t)^{\theta_2}$$

The abatement cost equation in (6) is a reduced-form type model in which the costs of emissions reductions are a function of the emissions reduction rate, $\mu(t)$. The abatement cost function assumes that abatement costs are proportional to output and to a power function of the reduction rate. The cost function is estimated to be highly convex, indicating that the marginal cost of reductions rises from zero more than linearly with the reductions rate. (Nordhaus 2014)

Part 2 – Discussion on the Econometric Model Choice and Analysis

1 – Table A.1 shows the correlation matrix of the dependent and independent variables for the estimated panel linear model for High income countries.

Table A.1 - Correlation Matrix for HICs

	Carbon Emissions	GDP Per Capita	Imports	Exports	Urban	Year
Carbon Emissions	1	0,0856	0,8121	0,6978	0,9569	0,0169
GDP Per Capita		1	0,1846	0,2195	0,0544	0,3774
Imports			1	0,9651	0,8599	0,34815
Exports				1	0,7747	0,4129
Urban					1	0,0604
Year						1

2 – Table A.2 shows the correlation matrix of the dependent and independent variables for the estimated panel linear model for High income countries.

Table A.2 - Correlation Matrix for MICs

	Carbon Emissions	GDP Per Capita	Imports	Exports	Urban	Year
Carbon Emissions	1	-0,0868	0,8785	0,8896	0,8969	0,1721
GDP Per Capita		1	-0,0774	-0,0516	-0,0736	-0,0753
Imports			1	0,6381	0,3491	0,7511
Exports				1	0,4436	0,0268
Urban					1	0,1702
Year						1

3 – Table A.3 shows the results from the panel linear model regression of dependent variable (Carbon Emissions) on the independent variables (GDP Per Capita, Exports, Imports and Urban Population) to see the random effects. (For HICs)

Balanced Panel: n=17, T=30, N=510

Effects:

	Var	Std.dev	share
Idiosyncratic	0.02732	0.16530	0.279
Individual	0.07052	0.26556	0.721

Theta: 0.8871

Residuals

Min.	1st Quantile	Median	3rd Quantile	Max.
-2.50000	-2.4800	-0.0621	0.0124	0.0819

Coefficients :

	Estimate	Standard Errors	t-value	Pr(>|t|)	
log (GDP PC)	-31.306349	7.588446	-4.1255	4.328e-05	***
log (GDP PC)²	7.094128	0.559041	12.6898	<2.2e-16	***
log (Exports)	-0.323453	0.029114	-11.1100	<2.2e-16	***
log (Imports)	-0.189558	0.066684	-2.8426	0.004656	**
log (Urban)	-0.082572	0.074457	-1.1090	0.267963	
log (Urban)²	0.230695	0.801347	0.2879	0.773554	

Total Sum of Squares: 36.892

Residual Sum of Squares: 14.473

R-Squared: 0.6077

Adj. R-Squared: 0.60303

F-statistic: 129.866 on 6 and 503 DF, p-value: < 2.22e-16

4 – Table A.4 shows the results from the panel linear model regression of dependent variable (Carbon Emissions) on the independent variables (GDP Per Capita, Exports, Imports and Urban Population) to see the fixed effects. (For HICs)

Balanced Panel:	n=17,	T=30,	N=510		
Residuals					
Min.	1st Quantile	Median	3rd Quantile	Max.	
-2.4400	-0.0564	0.0062	0.0747	0.4660	
Coefficients	:				
	Estimate	Standard Errors	t-value	Pr(>|t|)	
log (GDP PC)	6.70959441	0.57801382	11.6080	<2.2e-16	***
log (GDP PC)^2	-0.29592893	0.03252762	-9.0978	<2.2e-16	***
log (Exports)	-0.21521025	0.07057492	-3.0494	0.002418	**
log (Imports)	-0.00231362	0.08339569	-0.0277	0.977879	
log (Urban)	0.44180263	0.96240875	0.4591	0.646396	
log (Urban)^2	0.00038697	0.02930476	0.0132	0.989470	

Total Sum of Squares: 23.03
Residual Sum of Squares: 13.307
R-Squared: 0.42222
Adj. R-Squared: 0.39612
F-statistic: 59.3128 on 6 and 487 DF, p-value: < 2.22e-16

5-Box A.1 shows the results of Hausman Test (As a result of which the fixed effect model **would have been** chosen)

Hausman Test

Data: HICR
chisq = 68.695, df = 5,
p-value = 1.915e-13
alternative hypothesis: one model is inconsistent

6-Box A.2 Shows the results of the for the fixed effects model to investigate the presents of heteroscedasticity in the unobserved errors (The results of the studentized Breusch-Pagan Test) – Which does not provide any evidence for the presence of heteroscedasticity.

studentized Breusch-Pagan test

data: fixed
BP = 10.213, df = 6, **p-value = 0.116**

7-Box A.3 Shows the results of the for the fixed effects model to investigate the presents of serial correlation in idiosyncratic errors (Breusch-Godfrey/Wooldridge test for serial correlation in panel models) – as a result of which the null hypothesis of no idiosyncratic correlation is rejected.

Breusch-Godfrey/Wooldridge test for serial correlation in panel models

data: Y5 ~ X5
chisq = 168.14, df = 30, **p-value < 2.2e-16**
alternative hypothesis: serial correlation in idiosyncratic errors

8-Box A. 4 Shows the results of the test for cross-sectional dependence in the fixed effects model. (Pearson CD test) – As a result of which, we reject the null hypothesis of no cross-sectional dependence.

Pesaran CD test for cross-sectional dependence in panels

data: Y5 ~ X5
z = 6.5662, **p-value = 5.163e-11**
alternative hypothesis: cross-sectional dependence

9-Table A.5 shows the results of the panel linear model regression for fixed effects correct with White's Panel corrected standard errors due to the presence of serial correlation in the idiosyncratic errors

Balanced Panel:	*n=17,*	*T=30,*	*N=510*		
Residuals					
Min.	1st Quantile	Median	3rd Quantile	Max.	
-2.4400	-0.0564	0.0062	0.0747	0.4660	
Coefficients	:				
	Estimate	Standard Errors	t-value	Pr(>|t|)	
log (GDP PC)	6.70959441	1.17167053	5.7265	1.796e-08	***
log (GDP PC)^2	-0.29592893	0.07073292	-4.1838	3.402e-05	***
log (Exports)	-0.21521025	0.17213722	-1.2502	0.2118	
log (Imports)	-0.00231362	0.14855051	-0.0156	0.9876	
log (Urban)	0.44180263	2.85116406	0.1550	0.8769	
log (Urban)^2	0.00038697	0.08324180	0.0046	0.9963	

Total Sum of Squares: 23.03
Residual Sum of Squares: 13.307
R-Squared: 0.42222
Adj. R-Squared: 0.39612
F-statistic: 59.3128 on 6 and 487 DF, p-value: < 2.22e-16

10-Box A.5 Shows the results of the for the first differenced model to investigate the presents of heteroscedasticity in the unobserved errors (The results of the studentized Breusch-Pagan Test) – It does not provide any evidence for the presence of heteroscedasticity. (Results for HICs)

studentized Breusch-Pagan test

data: fd
BP = 10.213, df = 6, **p-value = 0.116**

11-Box A.6 Shows the results of the for the first differenced model to investigate the presents of serial correlation in idiosyncratic errors (Breusch-Godfrey/Wooldridge test for serial correlation in panel models)

– It does not show any idiosyncratic correlation between the unobserved errors. (Results for HICs)

Breusch-Godfrey/Wooldridge test for serial correlation in panel models

data: Y4 ~ X4
chisq = 13.255, df = 30, p-value = 0.9965
alternative hypothesis: serial correlation in idiosyncratic errors

Part 3 – R-Codes

Box A.7 - Contains the R codes used for the econometric analysis

```
histo1 <- hist(res2,col = "red", breaks=200)
xfit<-seq(min(res2),max(res2),length=80)
yfit<-dnorm(xfit,mean=mean(res2),sd=sd(res2))
yfit <- yfit*diff(histo1$mids[1:2])*length(res2)
lines(xfit, yfit, col="blue", lwd=2)
qqnorm(res2)
qqline(res2)
histo1 <- hist(res4 ,col = "red", breaks=80)
xfit<-seq(min(res4),max(res4),length=80)
yfit<-dnorm(xfit,mean=mean(res4),sd=sd(res4))
yfit <- yfit*diff(histo1$mids[1:2])*length(res3)
lines(xfit, yfit, col="blue", lwd=2)
qqnorm(res4)
qqline(res4)

lte <- lo g(te)
lgpc <- log(gpc)
lexp <- log(exp)
limp <- log(imp)
lurb <- log(urb)
lgpc2 <- lgpc*lgpc
lurb2 <- lurb*lurb
Y <- cbind(lte)
X <- cbind(lgpc, lgpc2, lexp, limp, lurb, lurb2)
pdata <- plm.data(MICR1,  index = c("Country", "Year"))
fdMICR1 <- plm(Y ~ X , data = pdata, model = "fd")
summary(fdMICR1)
coeftest(fdMICR1, vcovHC(fdMICR1, type = "HC0"))
coeftest(fdHICR1,vcov=vcovHC(fdHICR1,type="HC0",cluster="group"))
coefci(fdMICR1)

bgtest(fixed1)
bptest(fixedok)
pcdtest(fixedok, test = c("lm"))
pcdtest(fixedok, test = c("cd"))
library(dyn)
pbgtest(fixed1)
phtest(fixed,random)

library(tseries)
library(adf.test)
install.packages("epiR")
library(epiR)
install.packages("TTR",repos = c("http://rstudio.org/_packages", "http://cran.rstudio.com"))
Panel.set <- plm.data(HICR1, index = c("Country", "Year"))
adf.test(lurb, k=1)
help("adf.test")
```