Economic Consequences of the Recent Climate Change

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Abstract. The paper tries to summarize the tangible effects of the climate change that has been documented so far. An enormous gap between rationales obtained from the real world and conclusions drawn from the presumptions has been identified. There exists a mixed empirical evidence of benefits and harms caused by the climate change. Most of the evidence is local. There exists no study that would seriously take on a topic of cost-benefit analysis of climate change on the global scale.

Keywords: climate change, cost-benefit analysis, literature review

JEL Classification: Q51, Q54

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Introduction

Climate change seems to be an important issue for both researchers and policymakers. Vast numbers of reports assessing consequences of climate change have been prepared as results of numerous research projects. Notably, almost 700 pages long "The Economics of Climate Change: The Stern Review", a report written as guidelines for British government, stands for the epitome of how economics is combined with climate change in the contemporary science (see Stern 2007). This report provides readers with scenarios for Earth's climate development within the forthcoming century and assesses impacts of the changes as well as mitigation and adaptation costs. Like virtually all other reports on economics of climate change, the Stern Review skips the fact that the global climate change is an ongoing phenomenon and that thanks to increased concentration of greenhouse gases, the climate has been already changing since the Industrial Revolution. Since then, an increase in the global temperature, a rise in the sea level, changes in precipitation, and their impacts on wildlife have been observed. These changes raise a striking question: what are the economic consequences of recent climate change? It seems obvious that making projections requires use of historical data. However, neither the Stern Review nor virtually all other reports on economics of climate change even mention these recent phenomena and their impacts on human societies.

The goal of this study is to make a review of the evidence of recent climate change, to evaluate them from the perspective of economics and to recognize blank areas that need to be filled with knowledge before building comprehensive model of economic consequences of climate change.

Literature evaluating environmental consequences on recent climate change encompasses thousands of papers. They are reviewed and summarized in several reports. The report that seems to be the most comprehensive and influential is the Fourth Assessment Report (FAR) of Intergovernmental Panel on Climate Change (IPCC 2007). The literature analyzed in the review you are now reading, originates in the references list of the first chapter of Working Group II Report, as a pre-selected sample of the most influential and the most recent papers on the topic. This sample has been enriched with a few arbitrarily chosen papers so as to make the survey more up-to-date (the report dates back to 2007 so it does not include the most recent findings) and more relevant to economics. Please note that this is a survey of the most recent literature rather than most important literature, since references in FAR do not include papers that were used to prepare previous IPCC's assessment reports.

There were 116 publications that seemed to be useful for a survey on economic consequences of climate change. They come from 66 journals, 2 books and 7 other sources like reports or materials from conferences. Table 1 contains the list of journals that published papers included in the survey.

Journal title	Number of papers
Science	9
Nature	6
Climatic Change	4
Environmental Health Perspectives	4
Journal of Coastal Research	4
Proceedings of the National Academy of Sciences of the United States of America	4
Global Change Biology	3
International Journal of Biometeorology	3
Journal of Climate	3
Natural Resource Modeling	3
Agricultural and Forest Meteorology	2
American Journal of Epidemiology	2
Ecology	2
Epidemiology	2
Geophysical Research Letters	2
Journal of Hydrology	2
Journal of Hydrometeorology	2
Philosophical transactions of the Royal Society of London. Series B, Biological sciences	2
Acta Tropica	1
AMBIO: A Journal of the Human Environment	1
American journal of enology and viticulture	1
American Journal of Public Health	1
Blood pressure monitoring	1
Canadian Journal of Earth Sciences	1
Canadian Journal of Fisheries and Aquatic Sciences	1
Canadian Medical Association Journal	1
Climate Research	1

Clinical & Experimental Allergy	1
Ecological Applications	1
Ecological Research	1
Emerging Infectious Diseases	1
Energy Conversion and Management	1
Environmental Research	1
Estuarine, Coastal and Shelf Science	1
Geomorphology	1
Geophysical Journal International	1
Global and Planetary Change	1
Global Change & Human Health	1
Global Ecology and Biogeography	1
ICES Journal of Marine Science	1
International Archives of Occupational and Environmental Health	1
International Journal of Climatology	1
International Journal of Epidemiology	1
International Journal of Medical Microbiology	1
International Journal of Sociology and Social Policy	1
Journal of Applied Ecology	1
Journal of Coastal Conservation	1
Journal of Epidemiology and Community Health	1
Journal of Fish Biology	1
Journal of Vegetation Science	1
Lancet	1
Malaria Journal	1
Marine Biodiversity	1
Marine Geology	1
Natural Hazards	1
Natural Hazards Review	1
Nature Reviews Microbiology	1
North American Journal of Fisheries Management	1
Ocean & coastal management	1
PLoS Medicine	1
Reports on Polar and Marine Research	1
Theoretical and applied climatology	1
Trends in Parasitology	1
Tropical Medicine & International Health	1
Weather and Forecasting	1
Wetlands	1

Total	107

Table 1. Journals ordered by numbers of papers used in this survey.

Economics is a science of allocation of scarce resources. Based on this point of view, the survey tries to summarize how climate change affects resources in their broad meaning. Every such a thing that is not abundant and that can influence people's utility can be treated as a resource. Even if some of those "resources" cannot be directly traded (like human health), there are other tradeable resources that can be given up in order to increase those untradeables. Hence, the comprehensive analysis of economics of climate change should include not only tangible material losses caused by floods, droughts, or hurricanes but also the effects on human health and all other issues affecting human lives.

The climate change influences the economies in several ways. On one hand there is a "real climate change", a phenomenon that is only slightly understood by contemporary science, including its origins, underlying mechanisms, and potential outcomes. This phenomenon influences average temperatures, sea levels, ranges of species, abundance of species, ecosystem productivities, etc. and in turn influences human lives. On the other hand there exists a "notion of climate change", i.e. models of what is actually going on, kept in minds of scientists, policymakers and regular citizens. These models are always far from perfection and often completely wrong in their assumptions and conclusions, which is a result not only of individual ignorance but primarily of the aforementioned lack of scientific knowledge and understanding of the topic. Nevertheless, the notion of climate change also influences human societies, often much stronger than the real climate change, in form of policies, subsidies, bans, taxes, social campaigns, etc. The job of a researcher is here to tighten the bond between the reality and ideas, by shaping the latter so that they resemble the former.

The objective of this study is to survey literature on consequences of recent climate change rather than on the climate change itself. Therefore the following four axioms underlie the study, without being discussed or justified:

1. Global climate change does exist and is primarily expressed by an increase in Earth's mean temperature of the air in the lower parts of the atmosphere.
2. Greenhouse gas concentration, especially carbon dioxide, increases together with the mean temperature mentioned above.

3. Increases in temperature in turn affect other climatic variables like humidity, precipitation, windiness, and many others.
4. Global climate change can be broken down into regional climate changes, as the changes in the planetary climate are not distributed evenly. Regional climate changes are very heterogeneous and not necessarily resemble global trends.

Please note that there is no assumption about origins of the increase in concentration of greenhouse gases and about its causal relation with global climate change. Study is interested in effects of those phenomena, not in the relations between them or in their origins.

In this survey, I am deliberately omitting some environmental effects that don't have much to do with the economy. Biodiversity helps economic development, for instance by allowing people to industrially replicate biological processes. However, there is no certainty that extinction of particular species of toads endemic to some areas is relevant to economic development. And even if it is, the potential influence is virtually not possible to be measured.

On the other hand, some brief summary of environmental issues is needed so as to build up a whole picture. Changing environments can be a prelude to changing economies, for example change in the environment may allow introduction of crops. Therefore, whenever possible, I also try to include papers, whose implications at the first glance do not have much to do with the economy, but may be economically relevant in indirect way.

The survey consists of seven chapters. In the first two chapters issues relevant to human health are discussed. The first deals with heat waves and cold spells affecting human health trough increased mortality rates, the second deals with recent trends in patterns of diseases' incidence attributed to the changing climate, especially vector-borne disease like malaria. In the third chapter the effects if an increase in the sea level are discussed. The focus is placed upon coastal erosion and degradation of coastal marshes. The next chapter presents evidence on how regional climate changes affected fisheries in terms of availability of fish stock, usually governed by shifts in range of habitats. The fifth chapter describes how the regional climate changes affected crop cultivation as well as other activities that depend on biological resources highly vulnerable to climate shocks (e.g. droughts), like herding or forestry. The subsequent chapter discusses trends in occurrence of extreme events such as hurricanes, storms, floods and trends in related economic damage. In the final chapter, there is a short presentation of evidence of property damage caused by melting of permafrost and some facts of skiing industry being under the pressure of depleting winter snow cover. The survey ends with conclusions where I am trying to sum up the facts and present my point of view over the issue of the global climate change and its economical aspects.

Mortality caused by heat and cold

The most direct impact of the climate change on human wellbeing is by affecting their mortality. Indeed, there are a lot of studies employing econometric methods in order to find how temperatures relate to mortality rates. An example of such a study is a paper written by Carson, Hajat, Armstrong, and Wilkinson (2006). The authors analyze the seasonal pattern of mortality in London, United Kingdom, within 20th century. They use four periods, namely: 1900-1910, 1927-1937, 1954-1964, and 1986-1996, so as to avoid problems with pandemics of contagious diseases. For those four periods, they obtained four winter to non-winter weekly death rate ratios: 1.24, 1.54, 1.48, and 1.22. Furthermore, they broke down deaths into three categories by their cause:

1. cardiovascular diseases,
2. respiratory,
3. noncardiorespiratory.

The first category is commonly believed to be related to heat, however there exist studies claiming that heat lowers pressure and related cardiovascular risk (see Barnett et al. 2007). The second category is commonly attributed to cold weather.

Taking the death cause into account, the authors computed winter to non-winter weekly death rate ratios and they obtained the following figures for the three corresponding categories and for the four corresponding periods:

1. 1.30, 1.53, 1.45, and 1.23.
2. 2.05, 2.32, 2.70, and 1.59.
3. 1.07, 1.31, 1.23, and 1.10.

The general conclusion was that the vulnerability to fluctuations in temperature is decreasing over time (this conclusion is consistent with other papers, for example Davis, Knappenberger, Novicoff, and Michaels 2003b or Donaldson, Keatinge, and Näyhä 2003). However, while analyzing such figures for a particular area, one should keep in mind specific features of the region under scrutiny and its history. It is worth noticing that the medical progress heavily influenced the distribution of deaths among the population. The children under 15 accounted for 38.5% and 1.5% of deaths in the first and in the last period respectively, and the corresponding figures for elderly aged 65+ are 29.4% and 79.7%. Moreover, technological progress which encompasses among others heating and air conditioning might have contributed to overall decrease in mortality due to extreme heat or cold (this claim is also supported by Kunst, Looman, and Mackenbach 1991). Britain itself is an area with high excess winter mortality (even higher than in some countries in continental Europe with more severe winters). Figure 1 shows how excess winter mortality evolved over the past 60 years in England and Wales.

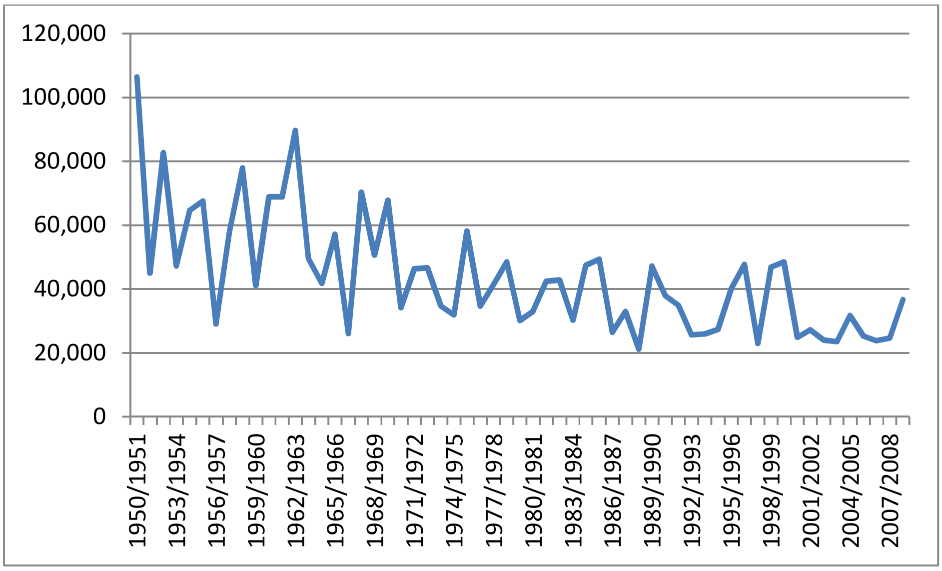

Figure 1. Excess winter mortality in England and Wales between 1950 and 2009. The number on a vertical axis is a difference in number of deaths during the four winter months (December to March) and the average number of deaths during the preceding fall (August to November) and following summer (April to July). Source: http://www.statistics.gov.uk/statbase/ssdataset.asp?vlnk=7090.

Likewise in United Kingdom, excess winter mortality is prevalent in developed countries and is statistically significant and high even in countries with Mediterranean climates like

Portugal or Greece (Haley 2003). All of the following countries have average winter weekly mortality higher than 110% of annual weekly average: United States, Japan, Italy, France, Spain, Canada, Australia, Sweden, Greece, New Zealand, and Cyprus (Falagas et al. 2009).[2]

Nevertheless there exist papers that claim that heat is a primary weather-related cause of death, for instance Davis, Knappenberger, Michaels, and Novicoff (2003a). In this paper author suggest that the climate change may contribute to an increase in heat-related mortality. On the other hand, they admit that the sensitivity to exceptionally high temperatures has declined since 1960s.

Davis, Knappenberger, Michaels, and Novicoff (2003a) were probably thinking about anomalies like heat waves and cold spells rather than correlation between ambient temperature and mortality throughout the year, while formulating their unfortunate judgment. In fact, there are a lot of papers examining impacts of those anomalies on human mortality. Heat waves are of a particular interest. Johnson et al. (2004) find that during the heat wave in England in 2003, there were 2091 excess deaths (the heat wave was 8 days long and was split into two intervals). Their paper emphasize that the death toll of the described heat wave is higher than the death toll of previous heat waves. The European heat wave in 2003 was the strongest heat wave since centuries taking away approximately 30,000 lives according to Trigo et al. (2005). Conclusions about increasing strength of such events are also reached by Diaz et al. (2002) who summarize heat waves in Madrid that took place between 1986 and 1997.

Another interesting paper, written by Kysely (2004), presents an analysis of heat waves in Czech Republic. The authors found an average gross 13% increase in mortality due to heat waves between 1982 and 2000. They also found that after a heat wave, mortality substantially decreases. Taking this phenomenon into account, the average net excess mortality caused by heat waves equals 1%. This unequivocally important finding is consistent with graphs in Johnson et al. (2004), however the authors seem to overlook it.

Huynen et al. (2001) belongs to a category of rare papers, where excess mortality during cold spells is analyzed together with death tolls of heat waves. The paper focuses on the area of Netherlands. According to their calculations, the excess mortality during heat waves between

[2] Note that winter in Australia and New Zealand are within the same period as summer in north-hemisphere countries.

1979 and 1997 was 39.8 deaths/day and during cold spells within the same period was 46.6 death/day. Cold spells were defined so as to be of similar frequency as heat waves.

Huynen et al. (2001) find a U-shaped relationship between mortality and temperature. The optimum temperature (i.e. the temperature with the lowest mortality) is 16.5 Celsius degrees. For every one degree increase in temperature, the mortality increases by 2.72% and for every one degree decrease in temperature, the mortality increases by 1.37%.[3] U-shaped relationship between temperature and mortality is also found by Curriero et al. (2002) who analyzed cities on US east coast; however their optimum temperatures exceed 20 Celsius degrees.

Aforementioned papers allow us to draw some general conclusions about the relation between recent climate change and the human mortality. There are two most important areas of study: seasonal patterns in mortality and excess mortality caused by heat waves and cold spells.

Seasonal pattern in mortality is dominated by the winter excess mortality, a phenomenon prevalent in many developed countries. Assuming that global climate change has increased both winter and summer temperatures, it is very likely that the observed decline in winter excess mortality can be partly attributed to recent global warming. However, the main reason of this decline was a medical and socio-economical progress. Therefore it is very hard to evaluate how many lives have been spared solely thanks to the climate change. Moreover, it is important to understand how the decrease in excess winter mortality relates to life expectancy. It may be a case that excess deaths in winter are deaths of people who are actually very close to passing away, and winter only makes it faster by a few months. On the other hand there may be people who die during the winter but would live several more years otherwise. These are the questions yet to be answered.

Heat waves are usually depicted as a severe tangible consequence of climate change. However, they are not much worse than cold spells that might have been mitigated by global warming. Moreover, heat waves in general have a little effect on human life expectancy as they

[3] Note that in Netherlands, average annual temperature is approximately 10 Celsius degrees.

take lives that are otherwise going to pass away soon anyway. It is still to be found out if the similar mechanism works for cold spells.

Finally, the vast majority of studies carried out on those topics are confined to developed countries. Therefore all the conclusion drawn in previous paragraphs may not (and are not likely to) be valid for developing countries, both because they are economically disadvantaged and because they are usually in geographical areas where weather has different impacts of human wellbeing.

Climate change and diseases

Climate change may affect human health through the development of pathogens by making the environment more suitable for them. Research focus is mostly on vector-borne diseases like malaria and diseases transmitted by ticks as well as on water- and food-borne diseases. Moreover, asthma and connection between climate change and allergens have also been under detailed scrutiny.

Malaria is the most broadly discussed disease in the literature. During a few last decades of 20th century there was severe malaria resurgence in some regions in Africa, which is believed by some scientists to be a result of global warming. Two of those regions were especially carefully studied, namely east African highlands and KwaZulu-Natal province in South Africa.

To understand the relationship between malaria and global climate change it is necessary to have some basic knowledge about how this disease is transmitted between hosts. Malaria belongs to a category of vector borne diseases, which means that it is transmitted by a particular kind of animal, namely female members of Anopheles genus of mosquitoes.[4] Mosquitoes lay their eggs in standing water, where they live as larvae before they reach adult form. After an infected vertebrate host has been bitten by an adult mosquito, the malaria parasites infect the body of their new host, eventually reaching its salivary glands after a few weeks. Then by biting another vertebrate, the mosquito spreads the disease. After a bite, it takes a few weeks to several months to develop the symptoms of malaria. They are usually headaches and fever. In severe cases, hallucinations, coma and even death may occur. The annual number of malaria cases is believed to equal nearly 250 million[5] and the death toll amounts to nearly 1 million, mostly of children under 5 years (WHO 2008). Malaria is believed to be both a result and a cause of impoverishment. Over time malaria developed resistance to some drugs which makes it harder to cure, therefore one of the most important ways to control malaria are vector control measures.

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[4] Male mosquitoes feed only on nectar. Female individuals can survive also on nectar only. Blood is needed so as to produce eggs.

[5] Data for 2006.

Research carried out in east African highlands is confined to the state of Ethiopia, Kenya and their neighbors. Abeku et al. (2003) find that malaria epidemics are more likely to occur when minimum temperatures in three preceding months are high. Rainfalls and maximum temperatures have no positive association with the epidemics. The connection between ambient temperature and malaria prevalence is also confirmed by Githeko and Ndegwa (2001).

On the other hand, Hay et al. (2002a) find that climate in East African highlands has not changed significantly during the past century; hence the increased number of malaria cases cannot be linked to regional changes in climate. This is confirmed by Shanks et al. (2002) and Hay et al. (2002b) who claim that probably drug resistance and decrease in vector control measures are the reasons for malaria resurgence. Their results are however challenged by Patz et al. (2002) who points out their methodological flaws. This work is followed by Pascual et al. (2006) where the authors present evidence for change in the regional climate in this area and for its significance for mosquito population.

A different point of view is presented by Zhou, Minakawa, Githeko and Yan (2004). The authors admit that the change in average temperatures in east African highlands was very small. However, the climate variability increased significantly between 1978 and 1998 and contributed to the number of malaria outpatients. Chen et al. (2006) suggest that also a change in land use patterns resulting from an increase in population density may be a reason for increased vector prevalence.

A slightly different situation took place in South Africa. The great resurgence of malaria was stopped in year 2000 by employment of anti-malaria policy introduced by the government. Craig, Kleinschmidt, Sueur, and Sharp (2004) analyze development of malaria between 1971 and 2001 in KwaZulu-Natal province in South Africa. The incidence increased significantly in the end of this period (which resulted in employing antimalarial policies in 2000). The researchers found that regional climate change is responsible for interannual variation of malaria incidence. The overall levels are driven mostly by non-climatic factors like drug resistance and HIV prevalence.

Barnes et al. (2005) describe the effects of the measures undertaken in the KwaZulu-Natal province to combat malaria. Thanks to improvement in vector control and anti-malarial treatment policies the outpatient visits related to malaria and paid to hospitals within the region decreased by 99% and malaria-related deaths had decreased by 97%.

Besides malaria, there are also other vector-borne diseases mentioned in the literature on consequences of the recent climate change. In temperate zones of the Northern Hemisphere, the overwhelming majority of vector-borne infections of humans are transmitted by ticks rather than insects (Randolph 2001). Two most renown diseases are tick-borne encephalitis (TBE) and lyme borreliosis (lyme disease).

Randolph (2001) examines incidence of those two tick-borne diseases in Central Europe. The paper confirms that recent trends in abundance of vector and incidence of the TBE disease are in agreement with theoretical models that link recent regional climate changes with biology of vectors and pathogens. The incidence decreased in southern countries (Croatia, Slovenia, Hungary) and increased in northern countries (Sweden and Baltic countries). However, this changes cannot be solely attributed to the climate change, as the changes in human behavior might have led to increased exposure to the pathogen. Article emphasizes that the incidence of Lyme disease can be related for example to aspects like reforestation, deer density, and land ownership.

Lindgren, Talleklint, and Polfeldt (2000) show that due to recent decrease in number of cold days in Sweden, distribution limits of ticks responsible for transmitting Tick-borne encephalitis and Lyme disease shifted northwards. Similarly, Lindgren and Gustafson (2001) prove that increase in incidence of TBE in Sweden in the 1980s and 1990s was related to regional climate change. Other factors also played a role. Among others: more people in endemic locations and increases in host animal population, the factors that are probably also related to climate change. Danielová et al. (2006) prove that in Czech Republic by the end of 20th century both tick and pathogens reached altitudes where they were previously absent.

Unfortunately, literature on this topic is not always free from ideology. Kovats et al. (2001) give us a good example of ideologically driven science. Even though the authors admit that "The literature to date indicates that there is a lack of strong evidence of the impact of climate change on vector-borne diseases", they try to argue that "This must be seen as 'absence of evidence' rather than 'evidence of absence' of an effect." They conclude that "New approaches of monitoring (...) are necessary in order to provide convincing direct evidence of climate change effects." Authors seem to be certain about their judgments even though they are in contradiction to contemporary empirical research and the authors themselves are unable to provide any empirical evidence justifying their assumptions.

Another health related impacts of climate change are allergies and asthma. Beggs (2004) provides us with an overview of the literature on pollen allergens. Recent climate change and increased concentration of CO_2 has caused a significant increase in production of allergic pollen (e.g. from ragweed or Japanese cedar).

According to Beggs and Bambrick (2005) prevalence of asthma increased in developed countries since 1960s significantly. In some countries the fraction of people suffering asthma even doubled between 1960 and 2000. This surge has been attributed to various environmental (air pollution) and lifestyle factors (especially so called "hygiene hypothesis" - less challenges to immune system in early life, but also change in diet or maternal smoking). However, according to the authors: "(...) any effects on asthma prevalence and morbidity could be compounded by changing pollen profiles (...) Climate change provides an additional plausible explanation for both increasing (...) susceptibility and (...) severity (...)" Authors focus on pollen-induced asthma which is believed to constitute over 70% of asthma cases. They mention four ways in which climate change is related to prevalence and severity of asthma:

1. Increased CO_2 concentration contributes to higher production of pollen.
2. Increased temperature contributes to higher production of pollen.
3. Increased temperature contributes to higher pollen allergenicity.
4. Extended pollen season due to changes in plant phenology.

Pollen distribution is not the only factor that may affect asthma prevalence. Gyan et al. (2003) describe a study of a Saharan dust transported over Atlantic Ocean to the island of Trinidad. Since 1970s, worsened drought in Sahara led to an increase in the amount of dust transported over the Atlantic Ocean. The authors find that there exist a correlation between air dustiness and number of pediatric asthma patients.

The last discussed impacts on human health that are related to global climate change are water- and foodborne diseases. For example Curriero, Patz, Rose, and Lele (2001) find that increase in outbreaks of waterborne diseases in the United States can be attributed to extreme precipitation events, which in turn are the effects of global climate change.

Foodborne diseases are also related to temperature according to D'Souza, Beeker, Hall, and Moodie (2004), who find that salmonellosis notifications depend on temperature and the incidence seasonality can by explained solely by changes in temperature. Between 1991 and 2001 in all of the 5 cities under scrutiny, an increase in salmonellosis notifications occurred.

Unfortunately, the picture of economic consequences that can be drawn according to the above findings is blurred. The ongoing discussion on malaria doesn't allow us to reach a final conclusion: did the recent climate change really contributed to the increase in number of cases (or increased costs of healing)? Other vector borne diseases are believed to be shifting northwards but there is no quantitative comparison of incidence in "newly-gained territories" and in "recently-lost-territories". Such a comparison is needed so as to evaluate if climate change is harmful or beneficial to human wellbeing.

Within surveyed literature, there were also no estimates on costs of healthcare. There is a really serious need for such estimation as the qualitative descriptions are not enough to place a weight on this issue as compared to other economical consequences of the climate change. The best way to deal with this issue would be to make a summary of all the diseases that can be influenced by meteorological conditions and to evaluate their costs of treatment and/or impacts on life expectancy. Studies of particular diseases in particular areas are important and necessary, however they are not enough to draw general conclusions and as policy guides.

Sea-level rise and related loss of land area

The notion of tragic sea-level rise caused by melting of glaciers and ice sheets and taking away huge coastal areas is prevalent in modern culture as induced by early science of climate change. According to Carminati, Doglioni and Scroccas (2005) the mean sea level rose by 195mm between January 1870 and December 2004. They found a rate of sea rise of 1.7 ± 0.3 mm/y and acceleration of sea level rise of 0.013 ± 0.006 mm/y^2 (however the acceleration cannot be inferred solely from the period between 1950 and 2000, for more details see Church et al. 2004). The most recent predictions for a next century estimate that the sea-level will rise for another 40 cm.

The literature on the topic focuses mostly on beach erosion and coastal wetlands erosion. Beach erosion means a loss of land that is covered by advancing sea. A perfect example of a paper dealing directly with this phenomenon is provided by Allan and Komar (2006), who examine the effects of the sea-level increase along the western US coast. They collect data from wave buoys and find that between 1975 and 2000 the sea advanced on average by 0.95 and 0.36 meters towards the coast in Northern Oregon and Los Angeles area respectively, meanwhile in Washington and Southern Oregon, the sea retreated by 1.9 and 1.0 meters respectively. The fall in relative sea level in the latter areas is caused by uplifting of the continental plate in the region.

Uplifting seems to play a great role in many places. E.g. Larsen et al. (2005) present an explanation for the rapid uplift of southern Alaska. The coast is uplifting at a rate faster than 10mm/y. The explanation provided by the paper is that collapse of Glacier Bay Ice Field released the landmasses that are now uplifting.

There are some more spectacular examples of coastal erosion. Lantuit and Pollard (2003) describe Hershel Island (next to Canadian Arctic Ocean coast) which between 1954 and 2000, due to rise in the sea level and thawing of permafrost was losing on average 0.89 meters of coast annually. Beaulieu and Allard (2003) in their study of Canadian coastline in Arctic also confirm high levels of coastal erosion.

Canadian subarctic coast is not densely inhabited and as a result, the value of the land being under loss is marginal from the economical point of view (but might be from the ecological point of view). However, there exist examples of coastal erosion that can be indeed linked to economical loss. Daniel (2001) provides us with an overview of beach replenishment (beach nourishment) practices in Delaware. According to the article, there are two main reasons for coastal erosion, namely rise in the sea level and storms. Current policies for mitigating coastal erosion cost approximately $1.8 million per year and are believed to be efficient in mitigating long-term effects of coastal erosion. Therefore $1.8 million can be used as a proxy for costs of coastal erosion. Unfortunately paper does not discuss how much of this sum can be attributed solely to effects of climate change (i.e. sea lever rise and increased frequency and/or severity of storms). Another such example is provided by Forbes, Parkes, Manson, and Ketch, who describe troubles of a beach in Alexandria due to the rise in the sea-level.

The sea level rise has also an impact on developing countries, where fighting coastal erosion may be too costly. Mimura and Nunn (1998) give an example of how rise in the sea level (combined sometimes with local activities like clearing the area close to the coast from plants) affects lives of people in developing countries. Costs of the rise in the sea level can be expressed as costs of building seawalls that allow villagers to reclaim the land taken away by the ocean.

The rise in the sea level is usually considered as a great threat to small islands and societies occupying them. Webb and Kench (2010) examine 27 low lying atoll Pacific islands using satellite images. 43% of the islands increased in size within last 19 to 61 years despite the sea level rise, 43% stayed the same and 14% decreased in size. Net changes are much smaller than gross changes, which according to the authors, depends on a variety of factors, not only the increase in the sea level.[6]

The coastal wetland erosion means usually salt marshes or mangrove swamps moving towards the land, or even being destroyed and turned into an open water. Among the papers dealing with this issue, majority are studies of a particular area where a distribution of coastal fauna has changed recently, often being measured thanks to satellite images. An example of such a study was done by Cooper, Cooper, and Burd (2001), a study on salt marsh in Essex county in England. Between 1973 and 1998, 10 km^2 of salt marsh has been lost due to coastal erosion. The importance of salt marshes is emphasized in the paper, as they are important for coastal defense and because of their ecological value. Similarly, Donnelly and Bertness (2001) report losses of salt marsh in New England due to the sea level rise.

According to Georgiou, Fitzgerald, and Stone (2005), coastal wetlands in Louisiana are turning into open bays due to the sea level rise. Average level of coast retreat in Louisiana was approximately 6 m/y between 1855 and 2002 and accelerated to 10 m/y between 1988 and 2002 (for more details, look Penland et al. 2005). Besides Louisiana, wetlands in South Florida are also under particular interest. Since 1940s, marshes on South Saline Everglades shifted

[6] Not that maybe if there hadn't been any sea level rise, the islands would have grown bigger than they have grown.

inland by 1.5-3.3 km which is partially attributed to the increase in the sea level (Ross et al. 2000).

Saintilan and Williams (1999) try to explain the reasons for landward transgression of mangroves and salt marsh in south-east Australia. The authors mention the following factors: increase in precipitation, agricultural practices, sea level rise, sedimentation and nutrients, and subsidence (in this particular order). Other studies on erosion of salt marshes has been carried out by Rogers, Wilton, and Saintilan (2006), van der Wal and Pye (2004), and Wolters et al. (2005).

In the aforementioned papers wetland erosion is usually attributed to the increase in the sea level, being an effects of the global climate change. However, there are also papers presenting a different point of view. Thampanya, Vermaat, Sinsakul, an Papapitukkul (2006) point out that most of the coastal erosion and mangrove loss in Thailand can be attributed to local human activities such as shrimp farming or building of dams that reduce riverine sediment input. They confirm that presence of mangrove reduce erosion rates. Their findings are in accordance with Hartig et al. (2002) who blame losses in amount of salt marsh near JFK Airport, NYC, on both the sea level rise and local activities like reduced sediment input, dredging navigation channels, and boat traffic.

Both types of papers, on beach and on wetland erosion tend to focus and a particular area, and there is no global summary that would assess the amount of lost land, let alone its value. Nevertheless, it is possible to make a rough estimate of this amount for particular areas. Assuming that average steepness of the coast is 0.05 (i.e. tangent of the slope), the 20 mm increase in the sea level means an advancement of water 4 meters towards the land.[7] Now this can be multiplied by the length of the beach (e.g. 20 kilometers) to get the loss of the land (8 hectares).

Note that only relatively flat coasts are susceptible to land loss. Moreover, if the beach is uplifting at a high speed, then a loss of land due to the rise in the sea level occurs even though relative sea level is decreasing. The land gain due to the uplift is diminished by water level, and this reduction of gain can be treated as a loss. On the other hand, uplift of

[7] Please note that this figures are just an illustration and they are not taken from any reliable source.

continental plates is frequently caused by melting of ice sheets, which in turn can be attributed to climate change. Hence, climate change can be in some areas responsible for the increase in available land although such situations are not common.

The useful thing in evaluating up-to-date consequences of the eustatic sea level rise would be a worldwide summary of:

1. Costs incurred in order to preserve beaches and other sorts of coasts in their present condition.
2. Area of land lost to the sea together with land values, expressing the total value of land lost.
3. Wetland losses (plus their direct economic consequences like damages caused by reduction in coastal protection against storms or decreases in seafood production).

Unfortunately, such summaries would be very hard to create. For instance, beach replenishment counters not only effects of increased sea level but also other factors of erosion. Therefore it would be necessary to attribute the right amount of erosion to the climate change in particular, which doesn't seem to be an easy task.

Fisheries

Fishery is a globally important industry. Annually almost 150 million tons of fish are harvested worldwide with approximately 2/3 of this amount coming from wild fisheries and 1/3 coming from fish farming. As most of the fish are still harvested in relatively primitive way (i.e. they are still caught in wild, as they were in ancient times when people were hunter-gatherers as opposed to more advanced farmers), the industry is highly vulnerable to climate change (see Hannesson 2007).

The literature on this topic can be divided into three categories. The first consists of papers discussing changes in fish phenology, their migration habits, and distribution that are at first glance not economically relevant (sometimes because the fish being scrutinized is not commercially exploited). Examples of papers in this category are Holbrook, Schmitt, and Stephens (1997), Juanes, Gephard, and Beland (2004), Quinn and Adams (1996), Elliott, Hurley, and Maberly (2000), and Legendre and Rivkin (2002) and they will not be discussed here.

The second category consists of papers that are dealing with fresh water fish habitats. Those papers usually examine population in particular area, for example within one river or lake. For example, Bartholow (2005) claims that elevated temperature pose a threat to recovery of salmonids living in Klamath River (Oregon and California), because too high water temperature is stressful to them. Another example give Hari et al. (2006) who say that increased temperatures in Alpine rivers forced an upward shift in habitats of brown trout. As physical barriers often limit the migration, the population of brown trout has indeed declined, which can be inferred from the catch data.

On the other hand there are also papers that link climate change with higher productivity. According to Schindler, Rogers, Scheuerell, and Abrey (2005), increases in temperatures between 1962 and 2002 in southern Alaskan lakes contributed to higher zooplankton densities and resulted in increased growth rates of juvenile salmonids.

The third and the richest category of papers consists of papers dealing with marine fisheries. The most extensive studies are carried out in North Atlantic Ocean, especially along the European coast. Other papers focus on subarctic parts of North Atlantic and on Pacific Ocean.

According to Brander et al. (2003), the temperature of the upper 300 m of North Atlantic increased by about 0.6°C between 1984 and 1999 with a great geographic and interannual variability. Perry, Low, Ellis, and Reynolds (2005) show that distribution of fish in North Sea shifted northward as a result of climate change.

Arnason (2007) and Brander et al. (2003) give an interesting example of variation in cod and herring stock in North Atlantic with respect to time and water temperature. Between 1930 and 1960 the abundance of those two species was much greater than nowadays. Then, after 1960, the stock decreased probably due to severe cooling of North Atlantic and to overfishing. Nowadays, the stock of herring started to recover after warming of waters in 1990s, but extensive areas of North Atlantic are still only marginally habitable for cod because water is too cold. This is however in contradiction to Beaugrand et al. (2003) who claim that increased temperatures in North Sea reduced survival rates of young cod because of drop in abundance of plankton.

Another evidence for increase in productivity (possibly) due to the climate change comes from Beare et al. (2004) who say that during the same warmer period (after mid 1990s), sardines and anchovies in this region that had been confined to southern Europe only, spread temporarily up north. Recently, both species are more and more frequently caught in proximity to the Scottish coast, probably as a result of climate change.

On the other hand, according to Beaugrand and Reid (2003), Salmon population in North Atlantic declined, especially since year 1990. This is related to changes in sea surface temperature and to changes in biogeography of phytoplankton and zooplankton also caused by warming of waters. However, there are some parts of North Antlantic, where at the same time (late 1980s) significant cooling occurred. This cooling contributed to a dramatic drop in abundance of capelin, off Newfoundland and Labrador (Canada), which is the main source of nutrients to commercially important cod. The cod population is now at its lowest in the recorded history, despite a fishing moratorium imposed in 1992 (see Rose and O'Driscoll 2002).

Less numerous studies focus on Pacific Ocean. Chavez, Ryan, Lluch-Cota, and Niquen (2003) present an overview of mechanism underlying changes in abundance of anchovies and sardines in this area. Anchovies are more abundant when water in the ocean is cooler and sardines are more abundant during warmer periods. Those periods are on average 25 years long and they subsequently occur after each other since the beginning of 20th century, resulting in so called "anchovies regime" and "sardine regime". Changes in abundance are so high that they spawn and destroy whole fishery industries (like sardine fishery industry off California before World War 2). They are related to internal mechanisms of the ocean and are related to phenomena like El Niño and La Niña. Relevance of the recent climate change to those variations is marginal, especially as the most recent anchovies cool period begun in the late 1990s.

The general conclusion that can be drawn from those papers is that abundance of fish depends mostly on interdecadal variability in ecological variables which is loosely related to and sometimes even inconsistent with the global climate change. This variability depends on other climatic forcings like El Niño, La Niña, shifts in currents etc.

Another important conclusion is about overfishing. Eide (2007) points out that management of fisheries is more important than effects of global warming. Reid and Edwards (2001) add that overfishing may be a primary reason for a poor status of fish stocks in North Sea and climate change can only exacerbate it.

The picture is again blurred. Papers usually give examples of depleting or increasing stock of a particular fish in a particular area. But these examples hardly ever consist of quantitative assessment of both gains and losses within particular area. From economical point of view it would be necessary to use such assessments in order to estimate value of the resources lost or gained. Another problem is that much of this variability cannot be attributed to the climate change and depends on other forces. The right attribution is then here an important issue yet to be resolved.

Agriculture and forestry

Climate has a great impact on production involving biological resources like plants and animals. The greatest influence is trough ambient temperature that affects phenology (timing of the events crucial for the growth of an individual plant or animal) and in turn quality and yield. Other factors, related to the anthropogenic climate change and important especially for agriculture, are rainfall and the fertilizing effect of carbon dioxide (the more carbon dioxide in the atmosphere, the faster plants grow).

In the literature I reviewed, there are many papers that deal with the above factors, except for the fertilizing effect of CO_2. There are also a few papers on wildfires in forests and diseases of cattle. This chapter includes also short review of droughts which affect all of previously mentioned industries: agriculture, forestry and herding.

An example study on agriculture is provided by Chmielewski, Muller, and Bruns (2004), who examine the changes in timing of growth events of fruit trees (apple, sweet cherry) and field crops (winter rye, sugar beet, and maize) in Germany. The phases of natural vegetation advanced a few days between 1961 and 2000. This changes are however not significant enough to have an impact on productivity. Another example is given by Robeson (2002) who shows that growing season in Illinois increased by approximately a week during the 20th century.

A few studies investigate major crops of the United States: corn and soybean. Feng and Hu (2004) examine changes of weather between 1951 and 2000 and their effects on yields of those crops. The authors found that during that period, the area of United States where those crops are most extensively harvested experienced an increase in precipitation which should have positively affected yields of both crops. However, the effects of changes in temperature are more ambiguous. Crops are sensitive to both minimum and maximum temperatures, both are stressful to crops when respectively too low or too high. Temperatures have also an impact on the duration of growing season which influences productivity. Moreover, some areas experienced an increase and some experienced a decrease in temperatures. According to Feng and Hu (2004) "Although the observed decrease of the average temperature (...) has favored an increase of corn and soybean yield, the temperature decrease also has caused decrease in corn thermal time[8] and soybean thermal time and could limit the yield." The authors focus then on corn yield in Nebraska and come to the conclusion: "(...) the change of precipitation during the growing season (...) and the decrease of the daily maximum temperature (...) have contributed to the increase of the corn yield." The paper also emphasizes the reduced risk of spring and fall freezing damage to crops. Unfortunately, there is no deeper quantitative analysis that would help to evaluate those benefits. The results of Feng and Hu (2004) are consistent with the results of Lobell and Asner (2003), who find that between 1982 and 1998 productivity of corn and soybeans in United States increased due to changes in climate, especially because of a decrease in temperatures.

An example of such a study in another developed country is provided by Moonen, Ercoli, Mariotti, and Masoni (2002) who analyze weather conditions in Pisa, Italy, between 1878 and 1989 and their suitability for crop cultivation. They found that extreme events (extreme temperatures, extreme rainfalls, frosts, floods, and droughts) have not changed in a way likely to negatively affect crops. They also found that risk of crop damage due to frosts or floods decreased and moisture availability has not changed despite a decreasing rainfall trend.

A substantial fraction of papers on agriculture in developed economies focus on viticulture. Jones (2005) deals with grape growing in western United States. Between 1948 and

[8] Thermal time, or Growing Degree Days is a number of days with temperatures favoring development of a particular plant.

2002, minimum, average, and maximum temperatures have been increasing. Moreover, the number of days with frosts declined, the last spring frosts are occurring earlier and the first fall frosts are occurring later. All those changes are favorable for grape growth and wine production. The author however avoids to conclude if those changes have made cultivation of grapes better or worse off. He points out that some "locations may have become too warm for existing cultivars resulting in unbalanced fruit and greater challenges in the wine making process. (...) a reduction in frost occurrence and longer growing season may impact hardening potential and change pest and/or disease severity or timing." The author did not explain what "challenges" he had in mind. The doubts of the author seems to be an unnecessary caution in formulating conclusions. Arguments in favor of an increase in productivity are formulated clearly, and argument in favor of decrease in productivity are formulated as suggestions or predictions. Nevertheless, any conclusions about net impact on yield cannot be drawn from this paper.

Jones and Davis (2000) are much more conclusive about wine production in Bordeaux, France, between 1952 and 1997. The authors concludes that: "the phenology (...) shows a tendency toward earlier events (...) Trends in grape composition at harvest (...) indicate (...) greater potential quality. (...) Vintage ratings have shown a general increase (...) knowledge of the phenological timing describes nearly half the variability in ratings (...)". Although the paper deals nicely with quality of produced wine there is not much said about impact of the climate change on yield.

Nemani et al. (2001) generally agrees with Jones (2005) that increase in temperatures had a positive impact on growing grapes. This paper examines climate and wine production in California between 1951 and 1997. The authors claim that change in climate (especially declining number of frost days) was responsible for both increase in yield and quality. According to their figures, the value of the grape crop in Napa valley increased from $640/ha in 1963 to $19600/ha in 1996. Unfortunately, the authors don't mention if they taken inflation into account or how much of this increase can be attributed to climate and how much to technological progress.

The literature on developing countries is not as rich as the literature on developed ones. In general, while in the latter the recent climate change has contributed to better agricultural conditions, in the former crop cultivation became harder. For example, according to Peng et al. (2004), the yield from an experimental rice field in International Rice Research Institute Farm, Philippines, between 1979 and 2003 decreased by over 10% as a result of increase in average minimum temperature (that is average nighttime temperature) within dry season.

Another example of a decline in yield give Ben Mohamed, Duivenbooden, and Abdoussallam (2002), who show that yield of millet in Niger dropped by approximately 12% between 1967 and 1998. The paper shows also for the same period an evolution of rainfall and temperatures that supposedly affected the yield. However, there is no significant trend in both of the variables (and their variability), hence the drop in yields cannot be attributed to the climate change. The authors seem to overlook this and claim that this relationship exists, as they are focused on past climate variability rather than trends and on making predictions rather than analyzing past.

The last example of a literature on developing economies provides Eakin (2000), who describes a situation of smallholder farmers in Mexico. Based on various sources of knowledge on the most recent history of Mexican agriculture, the paper argues that climate change is not the most important factor affecting productivity of Mexican small farmers. Aside from pests and diseases, the main concern for crop producers are socioeconomic conditions like government policy and availability of funds.

Very few articles deal with impacts of the climate change on herding. The only paper found in the reviewed literature was written by Purse et al. (2005) who attribute increased incidence of bluetongue among European cattle to the climate change. The increases in the temperature made the environment more habitable for vectors and pathogens. The paper gives a precise qualitative description of the recent epidemics of bluetongue in Europe, however fails to provide quantitative evaluation of incidence which is necessary to assess the importance and economic relevance of this disease.

There is also only a little literature on forestry and it relates mostly to wildfires associated with changes in temperatures and precipitation. Gillet, Weaver, Zwiers, and

Flannigan (2004) say that the climate change trough elevated temperatures contributed to occurrence of wildfires in Canadian forests. In 1980s and 1990s the annual burned area was more that 5 million ha greater than the average annual burned area prior to 1960. Unfortunately, Bergeron et al. (2004) reach exactly opposite conclusion, claiming that the rate of fires is now lower than before 1960.

Westerling, Hidalgo, Cayan, and Swetnam (2006) find a significant increase in frequency and severity of wildfires in western U.S. forests within 1970-2004 period. This trend has been related to early snow melts and increased temperatures and more frequent droughts, which are in turn associated with the climate change. According to Running (2006), annual expenditures by governmental agencies to fight wildfires had reached by the year 2006 $1.7 billion. Unfortunately there was no attempt to present a trend in expenditures and attribute them to the climate change.

Agriculture, herding and forestry are all affected by droughts. Drought is one of the most costly extreme events. Annual cost of U.S. droughts is estimated to equal $6-$8 billion. Andreadis et al. (2005) divide droughts into four categories: agricultural (related to soil moisture), hydrological (related to runoff and stream flow), meteorological (related to precipitation), and socioeconomic (excessive demand for water). The paper focuses on agricultural and hydrological droughts. According to this paper, between 1920 and 2003 there was a general drop in droughts severity and frequency (both agricultural and hydrological), however a single drought in early 2000s was the most severe drought of the examined period (this drought was much more severe in hydrological way than in agricultural way).

Another paper on droughts was written by Easterling et al. (2000) who found that there was no significant trend in droughts in the US and the drought in 1930s was the most severe within past few centuries.[9] Nevertheless, according to Dai, Trenberth, and Qian (2004) the global very dry areas (identified by Palmer Drought Severity Index based on precipitation and temperature) have doubled since the 1970s and the global very wet areas slightly declined.

Unfortunately there is no single paper that would deal with fertilizing effects of increased concentration of carbon dioxide. This effect is probably much harder to investigate

[9] This may appear to be in contradiction to Andreadis et al. (2005) however it is not, since Easterling et al. (2000) was published in the year 2000, before the great drought mentioned by Andreadis et al. (2005) took place.

than results of changes in temperatures and precipitation. Moreover, even the effects of the two latter are hard to evaluate. According to Feng and Hu (2004), in developed countries yield has been increasing for past 50 years, but the most important reason for it is technological progress (seed genetics, fertilizers). Therefore quantitative analysis of gains and losses caused by different climatic conditions may be here very difficult. It is however possible to figure out if there was a net gain or net loss caused by the change in climate (i.e. it is possible to find a direction but not a magnitude).

The best way to evaluate changes in crop yields would be to make controlled experiments in which crops are cultivated under different climatic conditions (artificially modified, e.g. in greenhouses) with the same, modern technology. Then, not only a direction but also a magnitude of net change could be evaluated. While conducting such research, it is important to keep in mind that some climatic conditions believed to have a great influence over the plants (like rainfall) only indirectly affects growth process and can have no influence at all if other variables stay the same (e.g. amount of soil moisture).

Another puzzling fact is that regional climate change patterns are not necessarily consistent with global climate change pattern. A perfect example is an impact of the climate change on corn and soybean yield in the United States, that increased as a result of a drop in the temperatures. This example shows that interregional variation is stronger than global trend and, while trying to evaluate effects of climate change on agriculture, one cannot simply apply global average trends to find if the changes are favorable for particular crops in particular areas.

Nevertheless, the general conclusion is that so far crops in developed economies benefited and crops in developing economies are worse off because of ongoing changes in the climate, although in developing countries other factors play sometimes a crucial role in determining industry productivity. Unfortunately, the literature on herding and forestry is not rich enough to make similar evaluation with respect to those two fields.

Extreme events

Many scientists claim that human induced climate change contributes to the increase in the number of extreme events that cause lots of economical damage. In general, climate extremes can be divided into two groups: 1) expressed in simple climate statistics, which are based on phenomena that occur every year, 2) extreme events that occur suddenly (see Easterling et al. 2000). The first group consists of minimum and maximum temperatures and extreme precipitation events. The second groups consists of events such hurricanes, floods, storms, droughts, heat waves, and cold spells. Droughts have been already discussed in the chapter on agriculture and heat waves and cold spells have been discussed in the chapter on health, so they will be treated here very briefly.

Increase in mean global temperatures is associated with stronger warming in daily minimum temperatures rather than in daily maximum temperatures. Therefore the temperature range is usually narrowing on the regional level. The numbers of frosts days decrease and numbers of extreme heat events do not show any trend (Easterling et al. 2000). These characteristics are however not evenly distributed all over the Earth. According to Tank and Konnen (2003), in Europe, between 1976 and 1999, there was a significant increase in the number high temperature extremes and much slower decrease in the number of low temperature extremes which resulted in increased temperature variability. Another, opposite example is Hong Kong, where according to Lam, Tsang, and Li (2004) temperatures have increased more during winter than during summer.

Easterling et al. (2000) claim that there is no trend in occurrence of heat waves.[10] The most notable feature of the heat wave history is their high frequency in 1930s (there were also great droughts in that period). The rainfall has increased over mid- and high-latitude regions and decreased over tropical and subtropical regions. The area of drought or excessive wetness have increased.

Excessive wetness may in turn cause more floods. Douglas, Vogel, and Kroll (2000) examined the trends in flood flows and low flows in the U.S. between 1939 and 1988. They found that there was no statistically significant trend in flood flow during this period. They found also an uprising trend in low flows in some regions of the U.S. which is attributed to recent increases in precipitation.

Milly, Wetherlad, Dunne, and Delworth (2002) find an increasing trend in number of exceptional floods (all over the world). However, they didn't find a trend in frequency of floods

[10] One should keep in mind that this paper has been published in the year 2000.

occurring regularly. They admit that: "Our detection of an increase in great-flood frequency and its attribution to radiatively induced climate change are tentative." Similar conclusions are reached by Huntington (2006) who says that "(...) empirical evidence to date does not consistently support an increase in the frequency or intensity of tropical storms and floods." No evidence on increase in floods is also mentioned by Svensson, Hannaford, Kundzewicz, and Marsh (2006).

According to Pielke, Downton, and Miller (2002), flood damage in the US has been increasing between 1926 and 2000. This publication provides a dataset which indicate an increase in both nominal and real values of the losses. One should note however that damage depends not only on frequency and severity of floods but also on the amount of infrastructure present in the flooded area. Therefore losses expressed as fraction of GDP would be a better indicator of the results of floods possibly attributed to the climate change. Such a time series is presented on Figure 2. Note that this does not take into account a progress in dealing with floods, i.e. costs of mitigating them (e.g. building water reservoirs) or costs of avoiding them (e.g. building the infrastructure in a place that would not be optimal if there was no floods).

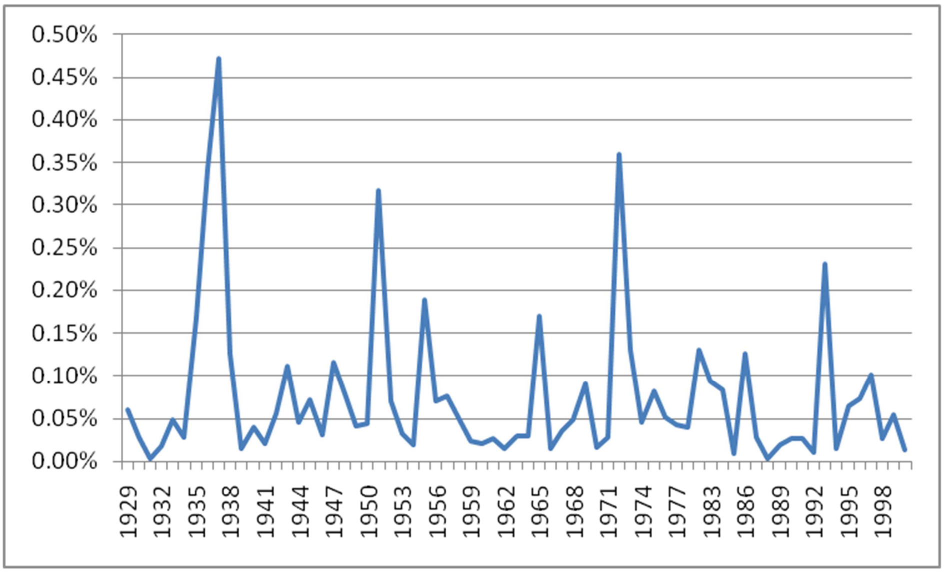

Figure 2. After combining nominal national losses caused by floods with nominal GDP in the US we can obtain a time series representing losses as a percentage of GDP. Source: values of losses come from Pielke, Downton, and Miller (2002) and values of nominal GDP come from http://www.bea.gov/national/index.htm#gdp.

This reasoning is supported by Easterling et al. (2000), who wrote that the damage caused by extreme events in the US, and expressed in money value has been increasing over the past few decades: "Annual hurricane losses have grown from $5 billion in 1940s to more than $40 billion in the 1990s (adjusted for inflation to 1990 dollars). Flood damages (...) continue to increase with annual losses of $1 billion in 1940s, growing to $6 billion per year during 1980s and 1990s (all in 1997 dollars). Damaging hailstorms causing urban losses in excess of $300 million have become common in the 1990s (....)". The paper however points out that "(...) weather events causing losses >$1 billion (1992 dollars) have not been increasing over time (...)". These statements are followed by the conclusion that "Most of the increase has been due to societal shifts and not to major increases in weather extremes. The growth of population, demographic shifts to more storm-prone locations, and the growth of wealth have collectively made the nation more vulnerable to climate extremes." Moreover, the number of deaths due to tornadoes, storms, and hurricanes have decreased or remained unchanged during 1980s and 1990s. On the other hand there are increases in mortality due to floods and heat waves.

Likewise, Pielke et al. (2003) analyze the case of Hurricane Mitch that killed more than 10000 people and caused over $8 billion in damage in late October 1998, mostly in Carribean countries. The paper concludes that the losses were incurred mostly because of the great increase in population during the inactive period from early 1970s to mid-1990s and they should not be attributed to the climate change.

Different point of view is presented by Muir-Wood, Miller, and Boissonnade (2006). According to their paper, there is an upward trend in economics losses from extreme events like hurricanes and floods between 1950 and 2005 (normalized with respect to GDP and inflation). The paper summarizes losses in several developed and developing countries. However, authors point out in the summary that 1) eliminating years 2004 and 2005 from the sample (i.e. eliminating major Atlantic hurricanes) or 2) eliminating China from the sample (due to its probably incomplete history on floods) makes the trend insignificant and reduces the significance of the trend in subsample between 1970 and 2005 to 10%.

From the above papers it is clear that the increase in concentration of human activities is the main reason of losses, not the increase in concentration of extreme weather conditions. Nonetheless, it doesn't rule out that increase in frequency or severity of extreme events played a role in this increase.

Emanuel (2005) says that the frequency of hurricanes shows no trend but their magnitude and potential destructivity have increased since 1970s. This is questioned by Landsea (2005) who shows that Emanuel (2005) made some methodological flaws and the investigation based on a longer time series shows that there is no trend in the destructiveness.

According to Easterling et al. (2000), the occurrences of Atlantic hurricanes show no significant trend over 20th century, although occurrences of most destructive hurricanes show downward sloping trend between 1944 and mid-1990s. In North Pacific the downward trend was replaced by upward trend after mid-1970s and since 1969 a strong downward trend is observed in Australian region, south to equator.

Goldenberg, Landsea, Mestas-Nuñez, and Gray (2001) find that between 1995 and 2000, North Atlantic hurricane activity was much higher than between 1971 and 1994.[11] The authors however point out that: "There have been various studies investigating the potential effect of long-term global warming on the number and strength of Atlantic-basin hurricanes. The results are inconclusive." and "The extreme activity in 1995 has been attributed in part to the record warm temperatures in the North Atlantic. (...) It is (...) possible that the current active period (1995–2000) only appears more active than the previous active period (1926–1970) due to the better observational network now in place."

Doubts about links between increased hurricane severity and the climate change are raised also by Webster, Holland, Curry, and Chang (2005), where the authors mention that there has been an increase in hurricane activity in North Atlantic but not in other areas. The paper points out that all the areas underwent increase in sea surface temperatures, so the

[11] Note that this statement is apparently in contradiction to the aforementioned claims of Easterling et al. (2000). This is however not true, as Easterling et al. (2000) deal with whole 20th century and Goldenberg, Landsea, Mestas-Nuñez, and Gray (2001) say only about increased activity in late 1990s after a period of inactivity in 1970s and 1980s.

increased activity in North Atlantic cannot be linked to an increase in SST as this claim is not supported by other basins. The greatest increase is among most powerful hurricanes.

Another paper on the topic was written by Landsea, Pielke, Mestas-Nuñez, and Knaff (1999) who say that there is no strong trend in both hurricane frequency and severity over North Atlantic and the interdecadal variability is more characteristic for this region. Likewise, Pielke and Landsea (1998) find no trend in hurricane activity within 1925-95 period in this area but instead they find a great interdecadal variability. This is supported by Zhang, Douglas, and Leatherman (2000).

The general conclusion that can be drawn from the papers on hurricanes is that there is no significant upward trend in hurricane frequency or severity. Even if such a trend existed it could not be attributed to an increase in sea surface temperature which is a direct link to anthropogenic global warming. Therefore, hurricanes cannot be included in the cost-benefit analysis of the recent climate change, even though they are very costly (most costly natural disasters in the US, see Pielke and Landsea 1998).

Similarly, no clear relationship between recent climate change and flood frequency or severity can be established. In general, like in case of agriculture, evaluation of currently incurred losses cannot tell us anything about costs of climate change. The record of history is blurred by other more important trends (especially in population and wealth) that affect those losses. Unlike in case of agriculture, controlled experiments cannot be here conducted; hence the only way to evaluate economic consequences climate change with respect to extreme events is to monitor their severity and to try to attribute this severity to climate change. This however has been so far unsuccessful.

Extreme temperature around the world are in general less and less extreme. On the other hand disparities in precipitation has been growing over time. This doesn't allow to come up with a general conclusion about the net direction of changes in terms of environment suitability for human economic activities. As in previous chapters, there is a huge gap in understanding and knowledge between observed changes in climate that for sure affected economy and quantitative evaluation of the effects of those changes. This is a huge area calling for more precise research.

Losses caused by melting and thawing

The last major topics that seem to be economically relevant are more direct effects of increases in the temperature on infrastructure and tourism (as opposed to indirect effects caused by e.g. the sea level rise). Damages caused to infrastructure related to global warming are often caused by thawing of permafrost. Papers dealing with tourism usually describe melting of snow that affects skiing industry in mountains.

Permafrost occupy approximately one quarter of the Earth's land area. Even though usually confined to subarctic and Antarctic areas, it is sometimes relatively highly populated and rich with infrastructure due to many mineral resources (especially in Siberia, Russia). Nelson, Anisimov, and Shiklomanov (2002) give some examples of a damage caused by thawing of permafrost. They are usually collapses of buildings, sometimes resulting in deaths and sometimes occurring over large areas (hundreds of buildings may be affected). Unfortunately, the paper gives no general summary of the losses.

Hamilton (2003) investigates the skiing industry in New Hampshire. The author finds that increase in temperature was resulting in decrease in snow cover and the occurring in 1970s collapse of many small enterprises, providing tourists with an opportunity to ski at southern and low-elevation locations. This is attributed to the climate change.

According to Laternser and Schneebeli (2003), snow depth, duration of snow cover and number of snowfall days in Swiss Alps were in an upward trend between 1931 and 1980s and then the trend reversed towards the end of the century. This is not directly stated in the paper but these changes probably had financial impacts on skiing industry in Swiss Alps. These impacts cannot be however easily attributed to global climate change because of the kink in the trend.

Unfortunately there is not much literature on any of those two topics. Therefore general conclusions cannot be drawn. The relevance of the topics is probably slight, especially compared to issues like agriculture, fisheries, or health, which is consistent with the numbers of papers on any of those subjects in the reviewed literature.

Conclusions

The literature on economic consequences of global climate change is seriously underdeveloped. On one hand there are many reports like the Stern Review trying to evaluate future consequences of climate change. These reports are not based on the up-to-date evidence and usually present gloomy visions of a hostile overheated environment and the collapse of the global economy. They hardly ever even mention about the fact that they may be some short-run advantages of the global climate change. They not only focus on short-term losses neglecting short-term gains, but also usually ignore the long-term effects at all. Especially they ignore the fact that after the new stable climatic equilibrium has been reached[12], there are potential gains and losses of such a magnitude that makes many short-run effects negligible. For example, a poleward shift in range of species with no doubt includes both a loss and a gain of territories suitable for agriculture.

On the other hand there are numerous papers trying to attribute various ongoing phenomena to the global climate change. These articles usually deal with particular locations. There is a lack of global reviews and summaries that would create a starting point for cost-benefit analysis of the climate change. Moreover, only few papers include some quantitative assessments of the incurred costs and/or obtained gains. Therefore the whole branch of science analyzing the economics of climate change is suffering from the enormous gap between rationales obtained from the real world and conclusions drawn from the presumptions. This undermines the reliability of contemporary economics of climate change as a science. Unfortunately this science is used to form policies that affect everyday life of people around the world.

The picture emerging from the recent consequences of the climate change is ambiguous and blurred.[13] Local trends, relating to particular areas and particular fields (like fisheries or

[12] The existence of stable climatic equilibria is essential for the whole debate on antropogenically induced global climate change. The currently observed and predicted trends in environmental variables that are supposedly effects of human activity are deviations from such equilibrium. If there were no such equilibria, the ongoing change would be just one within a sequence of natural changes. This survey is based on the assumption that a deviation from a stable climatic equilibrium is taking place.

[13] Keep in mind that the literature used for this survey stems from references used in the Fourth Assessment Report prepared by IPCC. This means that the literature is up-to-date but not necessarily complete. Papers included in previous IPCC reports are not included in FAR.

health) are often insignificant, let alone global trends that would allow us to evaluate net effects of the recent climate change. Moreover, the studies are so incomplete, that what we have got is like a few pieces of a puzzle scattered here and there with no possibility to infer what actually the image on the jigsaw is. Nevertheless, they allow us to draw some general conclusions, as incomplete as the evidence they are based on. These conclusions are the main goal of this survey since what we are really interested in is the future, which still can be changed, rather than the pasts, which cannot be changed, but provides us with insights into some mechanism that can be extrapolated into the future.

With no doubt regional variability in a majority of aspects is much greater that the global trends. As a result, recent evidence of regional climate change may be inconsistent with the global trends. This is particularly the case of the corn and soybean cultivation in the United States, where crop yields increased because of a decrease in temperatures. On one hand this lesson teaches us that the prediction of the future climate is not as simple as just adding global trend to the local climate. In fact, climate has a lot of internal variability that is often chaotic in nature as exemplified by the butterfly effect metaphor. On the other hand, at the first glance, it seems not likely that as the global average temperatures increase, in some regions the temperatures will continue to decrease. This, however, might be true if underlying complex climatic mechanism consist of the system of strong feedbacks.

Similar conclusions can be drawn from the change in fisheries. The papers described in this review indicate that those changes are related mostly to the internal mechanism of oceans and multidecadal cycles, and that the global trends have only a little influence on the environmental conditions in oceans supporting growth of fish. This may seem discouraging. What is the point of making global climatic predictions if, on a regional scale, they are absolutely neither reliable nor relevant? The answer is that fortunately the Earth has many local areas and according to the law of great numbers, the local variability should be irrelevant to the average net effect. The net effect is what we need for cost-benefit analysis.

The literature reviewed indicates that the recent climate change usually makes the temperature variability lower, by elevating minimum temperatures and leaving maximum temperatures as they were before. This is beneficial to the most of societies as the both biological and technological systems are designed to operate in average conditions and are usually stressed by extremes. Unfortunately, it doesn't look like a sustainable phenomenon. Strengthening of greenhouse effect will on average shift local temperatures (bot average and extreme) which will in turn result in average poleward shift of environmental conditions. The question that should be asked is if the most populated areas are going to benefit from this change or not. For example, increases in temperatures may cause higher mortality from diseases like malaria close to equator, but still more people may live in countries that would benefit from reduced winter mortality.

Poleward shift of environmental conditions means that large areas of land that is now unsuitable for agriculture can be in future utilized from crop production. Thawing of permafrost has negative short-run consequences like damage to existing infrastructure but in the long run it is beneficial as permafrost is a serious obstacle for plants to grow and for humans to build. The extent of the area covered by permafrost all over the world is really great and utilizing even a part of those terrains can be highly beneficial for human economies.

Retreat of the ice cover can also be beneficial. The depletion of sea ice on the North Pole as a result of the climate change can make shipping freight much easier. Moreover, the reduction of ice cover may allow people to access new mineral deposits. And there will be a gain in land value as uncovered soil is e.g. more suitable for building infrastructure than ice. Of course, there is a related threat: increase in the sea level[14]. This results in loss of land. What is important to evaluate, is the net effect of the melting of ice on the overall value of the land available. This would be a long-term economic result of ice melting. The damage caused to coastal infrastructure is only a short-run damage, as the infrastructure can be shifted landwards.

Long-term effects are clearly not as frequently presented in the literature on economics of climate change as they deserve. For example, all the effects on human health are in the long run negligible. Recent trends with regard to both winter excess mortality, heat waves mortality and mortality from diseases show that the technological progress dominates all other factors

[14] Another related threat is for example a change in water circulations. Especially glaciers are important sources of fresh water.

influencing human health. Moreover, the technological progress in these fields is highly independent to the climate change.

The above conclusions are highly incomplete and the gaps in knowledge are striking. There is a lack of knowledge on how the climate change has been affecting human lives in many regions and with respect to all aspects. There exists a huge gap between qualitative descriptions and quantitative assessments that are necessary to compute net effects and to design policies. A need for a comprehensive monitoring of the consequences of the ongoing climate change emerges. A good solution would be to construct a sort of a table which would divide the world with respect to regions and fields of study (e.g. human health, agriculture, etc.). This table could be systematically filled up and updated by researchers all over the world. Such a summarizing table would be extremely useful for making projections for future consequences of the climate change and for evaluation of policies. As for now, policies are based on presumptions rather than empirically obtained scientific data.

This leads back to an issue that has been addressed in the introduction to this survey: the discrepancy between the "real climate change" and the "notion of climate change". One of the most notable economic consequences of the climate change are not the effects of changing environment but the effects of policies introduced all over the world. Those policies include (but are not limited to):

1. Bans on certain consumption goods (for example ban on regular light bulbs in the European Union).
2. Subsidies to inefficient sources of energy (wind power plants, where production of electricity is sometimes even three times more expensive then from coal).
3. Taxes and quotas for production of certain goods.
4. Bureaucracy costs of governmental agencies enforcing market distortions.

All those policies in short run contribute to an inefficient use of scarce resources, hence contributing to a welfare loss of the peoples. Unlike the effects of the real climate change, they can be much easier evaluated and expressed as a loss in GDP. Making such calculations is however not a goal of this survey and the answer if those losses exceed tangible losses induced by the real climate change is yet to be answered, although I believe that the policy costs to date are much higher (even by an order of magnitude) than costs incurred due to changes in the environment.

The argument in favor of those policies is that they mitigate possible effects of the climate change (they trade short run costs for long run benefits). Governments are trying to protect their societies. Unfortunately it is not clear what to protect against i.e. what will be the magnitude and even the direction of forthcoming changes. Dismal projections are widespread and many scientists claim that even the greatest efforts are not going to reverse changes that will continue in the present century as a result of what have happened in the previous one. Such gloomy prospects are nothing new to economics, which is sometimes called a dismal science. What we can learn from the history of the notions that once doomed human societies is that not only a severe climate change but also a great incapability to adapt is required in order to make the economies indeed suffer.

Evidence on the recent climate change doesn't support the claim that the forthcoming global warming is going to be severe and/or harmful to the economies. In my opinion it is wasteful to try to prevent the climate change from happening since

1. evidence doesn't support its harmfulness,
2. it is likely inevitable.

It doesn't mean that there is nothing we should do about it. Most notably, there is a role for governmental intervention, especially to eliminate market failures. Most of these failures stem from the following two aspects of climate change:

1. imperfect information,
2. public good nature (or externalities).

The improvements in the information quality, i.e. more information on what actually is happening to the climate and how does it affect economies, is essential to adapt to the changes effectively. The government's role is not only to encourage research on the ongoing consequences of the climate change but also to encourage adaptation in form of promoting new technologies - technologies that are most efficient in the transition period and after reaching the new steady state, not the technologies that are inefficient and trying to prevent the transition.

It looks much more just and reasonable when resources are reallocated as compensation from the entities causing external costs to the entities being affected by those external costs rather than when resources are sacrificed in order to prevent something that probably may happen in the future. With improved information on the current changes, it is easier to identify causes and results of external effects related to the global climate change. This is how governmental intervention could occur: to make the emitters compensate for losses incurred by the businesses affected.

Other questions arise on the ground of fairness and morality. If we impose transfers from carbon dioxide emitters to industries suffering from the climate change, shouldn't we impose also transfers from industries that benefit from the climate change to carbon dioxide emitters? Should we transfer resources to suffering industries even though they are no longer efficient in the wake of the new climatic equilibrium? This would be a pure waste of resources. How do we then distinguish between businesses that deserve subventions from those that do not?

Questions multiply themselves and the situation gets complicated. Even with provision of almost perfect information such a system would be still challenging to implement e.g. because of possibilities of fraud. Much simpler solution would be just to try to provide as much information to the businesses as possible and to let them adapt on their own, by treating the climate change as it was exogenous. This may look unfair at the first glance. This is however they way the economy works: changing conditions drive rise and collapse of industries. And the availability of information that allows entrepreneurs to evaluate their future profits is a way to make the adaptation process easier and less painful.

Therefore, the "what to do?" question, given the current knowledge and the amount of uncertainty is: to devote resources to collect and reveal information on what is actually going on and to promote adaptation wherever it is needed rather than to mitigate the unavoidable.

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