Applied Mathematics and Computation 246 (2014) 586–596

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Analyzing and visualizing the synergistic impact mechanisms of climate change related costs

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ARTICLE INFO

Keywords:
Computational techniques
Mathematica computer software
Climate change related factors
Cost interactions

ABSTRACT

One climate related phenomenon could affect many more. The direct costs associated to climate related factors pass to a number of other climate related costs through the indirect economic consequences of climate change. In this paper we propose a mathematical model which aims to provide forecasts of the distribution of the costs caused by the synergistic mechanism of environmental effects. The model is created to be directly applied to situations where the primary costs associated to climate related factors can be specified. It is expressed in matrix terms and is programmed using *Mathematica*'s matrix functions. We provide the framework for efficient computation of this model, covering possible linear and nonlinear functions of the impact mechanism for costs and, infinite direct cost scenarios. Some directions for the quantitative estimation of impact indicators and adaptation potentials of the costs incurred by certain climate related factors are included, in order to apply the proposed model using real socioeconomic data.

1. Introduction

Societies depend entirely on ecosystems and the associated offered services like, among others, water and food provisions, operating in global biogeochemical cycling, raw materials and regulation of the climate [1–3]. The global climate change is a very complex issue and it is even more difficult to tackle and cope with due to its long-run character and the various synergistic effects stemming from its impacts. At the same time it is important to note that climate change may be considered as a public goods game. On the side of the industry, there are gains (profits) to be made by neglecting the emissions resulting from the industrial production; while in terms of the public goods in the form of the global climate, these public goods may be lost due to irresponsible and selfish behavior of the industry ignoring the social costs imposed and paying no attention to cleaner production. Studies concerning which factors could alleviate the tragedy of the commons and general suggestions of how a well-adjusted plan could mitigate climate change are made in [4,5].

It is also worth paying attention to the issue of collective behavior and evolutionary games with the term "collective behavior" referring to many different phenomena in the society and the nature [6]. Collective risk social dilemmas result when the contribution to the common pool within a group is small and the personal endowments are lost [7]. According to Chen et al. [8] the loss in personal endowments may be due to free-riding arising in a joint effort which fails to attain the collective target because of insufficient contributions. They also examine the emerging collective-risk social dilemma

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http://dx.doi.org/10.1016/j.amc.2014.08.044
0096-3003/

in the framework of the spatial public goods game with group-performance-dependent risk levels. Similarly, Szolnoki et al. [9] consider the achievement of cooperation in games describing social dilemmas, where the trend to follow a different strategy is a function of both individual readiness and fitness and the neighbours' strategies.

The synergistic impact mechanism of environmental effects produces the «colliding steel spheres effect», meaning that one climate related phenomenon could affect many more. In many environmental studies it is claimed that parallel interactions among climate effects is a possible situation [10–15]. In the report published by IPCC [10] climate change impacts are presented and analyzed on a matrix of potential for interactions and synergistic effects. Parson et al. [16] proposed a program of research analysis and methods development for climate-related impacts and vulnerabilities in the USA assuming that human activities and natural processes are closely linked.

In climate-modeling studies, several computable models have been proposed to compute the overall economic impacts of climate change; commonly used computable economic models for environmental issues are the computable general equilibrium (CGE) models. These consist of numerical models of all supply and demand relationships in an economy (as defined in [17] p. 8). Studies using a CGE approach to model impacts of climate change have been made among others in [18–24].

In the present study we generate visual schemes of the direct synergistic effects between climate related factors in several human settlement and industry types. Considering the primary costs caused by climate related factors, we assume that the synergistic impact mechanism among certain climate related factors allows for a similar synergistic impact mechanism of the corresponding primary costs.[1] With notations and operations of matrix algebra, using either a technical coefficient or a functional matrix to illustrate climate related cost interactions and synergistic effects, we formulate a local scale model that forecasts the cost distribution which the direct synergistic mechanism causes from the direct costs of certain climate related factors.

We create the computational framework to apply the proposed model in a qualitative and a quantitative approach. For this purpose a main computer algebra system, *Mathematica*[2] is used to generate our model's output, both visually and numerically. Specifically, in *Mathematica*'s computational environment, we create pattern constructs consisting of colored patches which describe the synergistic impact mechanism of climate related factors.

In this way, we provide initially a concise framework for synthesizing and displaying the data on an area's human-economic system. Then our predictive model is applied by using hypothetical data and *Mathematica*'s dynamic visualization options, in order to generate versions of cost distribution snapshots, with controls added to allow interactive manipulation for the value of impact indicators of cost interactions, the synthesis of the direct cost distribution and the amount of costs. Our model and its computational aspects allow for clear visual comparisons among certain settlement and industry types. The proposed model is well suited to perform sensitivity analyses in cases of settlements and industries and also to evaluate climate policies.

Finally, our contribution provides directions for quantitative estimates of impacts and adaptation potentials of the costs incurred by climate change related factors. It also ensures the model's applicability guiding for future applications on the economic costs of certain ecosystem inputs like migration, flooding–landslides–fires, air and water pollution, human health and energy by the use of available appropriate socioeconomic data.

The structure of the paper is the following. The next section discusses the visualization of the interactions first in the case of different settlement types and next to industry types. Section 3 proposes a linear and nonlinear cost analysis with different climate change scenarios and derives indicative estimates of the potential costs. Section 4 provides some insights in terms of performing an empirical application of the proposed model formulation while the last section concludes the paper.

2. Visualizing the interactions among climate related factors

2.1. The case of settlement types

Humans depend on the ecosystems and they are part of the ecosystems they live on [25,26]. Obviously a healthy ecosystem has the ability to sustain healthy human populations [27]. Most of the population in Earth lives in settlements in a way that their concentrations may result to vulnerabilities to local specific events. Vulnerability refers to the way a system reacts to the degradation imposed from its exposure to various risks.[3]

Human settlements and coastal zones are influenced significantly by coastal and riverine flooding, fires, etc. The risks and uncertainties of the consequences of global warming are of interest. The sea level rise will influence coastal areas and the use of land and may threaten the survival of some coastal communities. Extreme weather conditions and patterns leading to heat waves, floods and droughts change the climate condition of some areas with resulting consequences like storms appearing more often and more intensively.

The higher weather variability and the more extreme events may also affect the energy sector by increased demand for air-conditioning and reduced demand for space heating. This may be accompanied by the concern of electricity producers related to the reliability of their systems to cope with these changeable weather conditions [30]. Similarly, water

[1] Primary costs may be identified as direct costs while secondary costs may be considered as synergistic.

[2] *Mathematica* software is tradable from Wolfram Research, Inc.

[3] Vulnerability to effects of climate change may be defined as the degree a system, subsystem or system component experiences harm from its exposure to a perturbation or source of stress [28,29,11].