European Economic Review 94 (2017) 263–282

Contents lists available at ScienceDirect

European Economic Review

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

Climate change policy under polar amplification[☆]

W. Brock[a,b], A. Xepapadeas[c,d,*]

[a] Economics Department, University of Wisconsin, United States
[b] University of Missouri, USA
[c] Department of International and European Economic Studies, Athens University of Economics and Business, Greece
[d] Department of Economics, University of Bologna, Italy

ARTICLE INFO

Article history:
Received 2 June 2016
Accepted 9 March 2017
Available online 18 March 2017

JEL Classification:
Q54
Q58

Keywords:
Polar amplification
Spatial heat and moisture transport
Optimal policy
Emission taxes
Market discount rate

ABSTRACT

Polar amplification is an established scientific fact which has been associated with the surface albedo feedback and with heat and moisture transport from the Equator to the Poles. In this paper we unify a two-box climate model, which allows for heat and moisture transport from the southern region to the northern region, with an economic model of welfare optimization. Our main contribution is to show that by ignoring spatial heat and moisture transport and the resulting polar amplification, the regulator may overestimate or underestimate the tax on greenhouse gas emissions. The direction of bias depends on the relations between marginal damages from temperature increase in each region. We also determine the welfare cost when a regulator mistakenly ignores polar amplification. Numerical simulations confirm our theoretical results, while ballpark estimates indicate that the tax bias could be as high as 20%, while welfare cost could reach 2% of global effective steady-state consumption.

1. Introduction

A well-established fact in the science of climate change is that when the climate cools or warms, high latitude regions tend to exaggerate the changes seen at lower latitudes. This effect is called polar amplification (PA). According to the IPCC (2013, p. 396):

> "Polar amplification occurs if the magnitude of zonally averaged surface temperature change at high latitudes exceeds the globally averaged temperature change, in response to climate forcings and on time scales greater than the annual cycle."

PA is a global concern because of its possible future effects on ice sheet stability and the related consequences. Recent studies indicate the magnitude of PA. Bekryaev et al. (2010), using an extensive data set of monthly surface air temperature, documents a high-latitude (>60°N) warming rate of 1.36°C/century for 1875–2008, with the trend being almost two times stronger than the Northern Hemisphere trend of 0.79°C/century. The high-latitude warming rate accelerated in the most recent decade to 1.35°C/decade which is a manifestation of PA. Winton (2006) reports a mean annual Arctic (60° N–90° N) warming that is, on average, 1.9 times greater than the global mean warming at the time of carbon dioxide doubling. Similar

☆ We are grateful to the editors and two anonymous reviewers for valuable comments and suggestions on earlier drafts of this paper.
* Corresponding author at: Department of International and European Economic Studies, Athens University of Economics and Business, Greece.
E-mail addresses: wbrock@ssc.wisc.edu (W. Brock), xepapad@aueb.gr, xepapad@gmail.com (A. Xepapadeas).

http://dx.doi.org/10.1016/j.euroecorev.2017.03.003
0014-2921/

results for PA are reported by Serreze and Barry (2011) who point out that special attention should be given to the Arctic Ocean where the strongest amplification is expected to occur. The phenomenon of PA has therefore been well-established in the Northern Hemisphere, and is referred to as Arctic Amplification (AA). At the same time, most modern climate models project that increases in Antarctic temperature through the 21st century will be smaller than those in the Arctic, due to the very different geography of Antarctica (see Pithan and Mauritsen, 2014; Serreze and Barry, 2011; Stroeve et al., 2007, Fig. 1).

Regarding the mechanism causing AA, the discussion was initially focused on the surface-albedo feedback (SAF) which can be traced back to Arrhenius (1897). The SAF mechanism suggests that initial warming in the North Pole will melt some of the Arctic's highly reflective (high albedo) snow and ice cover. This will expose darker surfaces which will absorb solar energy, leading to further warming and further retreat of snow and ice cover. However, recent literature provides a variety of mechanisms other than SAF which can cause PA (see for example Graversen and Wang, 2009; Pithan and Mauritsen, 2014; Serreze and Barry, 2011). One of these mechanisms resulting from experiments undertaken by Alexeev (2003) and Alexeev et al. (2005) with an aqua-planet model without sea-ice and land-ice, and therefore without SAF, revealed that PA emerges as a result of an increase in the meridional heat transport. Langen and Alexeev (2007) interpreted PA as an inherent dynamical property of the system.

However, although PA is regarded by climate science as a near universal feature of climate model simulations of the planet's response to increasing atmospheric greenhouse gas (GHG) concentrations (e.g., Serreze and Barry, 2011),[1] this feature has been largely ignored by the economics of climate science. As pointed out by Dietz and Stern (2015), the science of climate change has been running years ahead of the economics of climate change. Moyer et al. (2014) made a similar point earlier and also stressed the importance of growth effects as well as level effects of climate change damages. The purpose of this paper is, therefore, to introduce PA and spatial heat transport into an economic model of climate change and explore their impacts on the design of climate policy in the form of carbon taxes. In this context, the present paper can be seen as extending the literature on the optimal taxation of GHG emissions by accounting for the PA effect, which is modelled by using a two-box model representing the heat transport from the Equator to the Poles. In the model, box 2 represents the higher latitudes (30–90°N) and box 1 the lower latitudes (0–30°N). This model is coupled with a simple welfare-maximization problem to derive the optimal GHG emission path in the two regions. The model we use is based on the two-box models of the meridional heat transport mechanism developed by Alexeev (2003), Alexeev et al. (2005), and Alexeev and Jackson (2013a, 2013b). Such models present mechanisms of heat transport, polar magnification, and ice line movement effects due to outside forcing along with a simple treatment of moisture transport.[2]

Three reservoir (or box) models describing the carbon cycle have been used in the economics of climate change (e.g. Gerlagh and Liski, 2016; Golosov et al., 2014; Nordhaus and Sztorc, 2013). In this paper, what we refer to as a two-box model is a model where boxes represent two geographical regions with heat and moisture transport from the low latitude region to the high latitude region. We keep the “two-box” terminology, following Alexeev (2003), but we emphasize that boxes refer to geographic regions and not to boxes or reservoirs for carbon diffusion. Four-box ocean models have been used to study emissions and abatement paths associated with a potential tipping point of the Atlantic thermohaline circulation (see Belaia et al., 2015; Zickfeld and Bruckner, 2008; Zickfeld et al., 2004). Our simplified two-box model does not include ocean boxes but allows us to study the link between damages and local temperatures and to characterize biases and welfare loss from ignoring PA when policy is designed.

In particular, if we denote the temperature anomaly – that is, the change in temperature relative to a given benchmark temperature – in each box or region by T_1 and T_2 respectively, the relaxation time of the box anomaly temperature gradient, $T_1 - T_2$, is faster than the relaxation time of the box anomaly global mean temperature, $(T_1 + T_2)/2$ (Langen and Alexeev, 2007, Eq. (23)). This difference is important in terms of economics since it is related to damages associated with temperature differences across different latitudes, in contrast to damages related to the planetary global average temperature. Therefore PA, apart from its importance for climate science, is also important for the economics of climate change and in particular the characterization of local damages and local policies.

We now briefly discuss costs and benefits associated with PA, in order to provide a clear picture of their importance. AA causes loss of Arctic sea ice which in turn has consequences for melting land ice along with other effects. According to the IPCC (2013, p. 9):

> “The annual mean Arctic sea ice extent decreased over the period 1979–2012 with a rate that was very likely in the range 3.5–4.1% per decade (range of 0.45–0.51 million km^2 per decade), and very likely in the range 9.4–13.6% per decade (range of 0.73–1.07 million km^2 per decade) for the summer sea ice minimum (perennial sea ice). There is medium confidence from reconstructions that over the past three decades, Arctic summer sea ice retreat was unprecedented.”

[1] As Langen and Alexeev (2007) indicate, PA is seen in model projections of future climate (e.g., ACIA, 2004; Holland and Bitz, 2003) and, in fact, in the very earliest simple model of CO_2-induced climate change (Arrhenius, 1897). PA is found in proxy-records of both deep past warm periods (e.g., Zachos et al., 2001 and of the more recent cold glacials (e.g., Masson-Delmotte et al., 2006).

[2] Brock et al. (2013, 2014b) use a more realistic energy balance model because it models the Earth by a continuum of latitudes and considers heat transport across latitudes, i.e., it has a “continuum of boxes” with heat transport across each. However, more advanced mathematics is required for this analysis.