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Spatial economic aspects of climate change

Amitrajeet A. Batabyal\textsuperscript{a} and Henk Folmer\textsuperscript{b}

ABSTRACT
The objective in this special issue is twofold. First, it emphasizes the importance of comprehending that, the global impacts of climate change notwithstanding, there are salient region-specific impacts that vary across space. Second, given this observation, it is shown how rigorous modelling of the connections between climate change and (1) land-use changes, (2) forestry, (3) infrastructure and (4) local labour markets sheds light on a variety of climate change-induced spatial economic effects. Following this introductory paper are seven additional papers in the issue. Each discusses a particular research question at the interface of what would be called ‘climate change and space’.

KEYWORDS
forestry, infrastructure, land use, local labour market, space

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THE PROBLEM STATED

A variety of gases such as CO\textsubscript{2}, methane, nitrous oxide and water vapour are now frequently referred to as greenhouse gases because, much like the glass in a greenhouse, they trap infrared radiation that would ordinarily escape into the Earth’s atmosphere. This entrapment tends to have a warming effect on the globe and the resulting ‘global warming’ can ultimately lead to climate change.\textsuperscript{1} As noted by Batabyal and Nijkamp (2019), there is little or no debate about the proposition that the greater the level of greenhouse gases, the greater the equilibrium temperature of the Earth. They also note that the expected functional relationship between greenhouse gases and the Earth’s temperature is expected to be non-linear, with the potential existence of one or more tipping points. In addition, there is virtually no debate about whether anthropogenic emissions of greenhouse gases cause a noteworthy rise in global temperature in comparison with present temperature levels, and in comparison with natural fluctuations in temperature levels. As noted by Kahn (1998, p. 167), the ‘debate centers around the magnitude and timing of the change, and its significance to human welfare’.

Even though the presence of fundamental uncertainty about many aspects of climate change (Nordhaus, 2013; Wagner & Weitzman, 2015) affects how researchers think about the underlying issues, it is fair to say that, in general, there are two broad ways of looking at and analysing the problem of climate change. First, one can look at climate change as an example of what economists

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call a global public bad (Hanley et al., 1997, p. 43) and then proceed to study the properties of and the difficulties faced in designing and implementing international environmental agreements (IEAs) between nations for the purpose of reducing greenhouse gas emissions. In fact, there is now a substantial literature on this topic, and economists in particular and social scientists in general have devoted a great deal of time studying why it is so difficult to secure agreement among nations to reduce the global emissions of greenhouse gases.

In the second way of conceptualizing and studying the climate change problem, researchers acknowledge the global dimension of the problem, but then point out that the regional impacts of climate change vary across space and are very likely to be dissimilar. This point has been made in the case of agriculture by Van Kooten and Folmer (1996) and others. Therefore, this dissimilarity calls for an explicit recognition of the fact that the region-specific effects of climate change pose region-specific problems that, in turn, require region-specific solutions. Although this fact has now been recognized by Ruth (2006), Ruth et al. (2006), Smith and Mendelsohn (2006), Calzadilla et al. (2007) and Karetnikov and Ruth (2014), it is fair to say that relative to the number of studies that have concentrated on the global dimensions of climate change, there are far fewer studies of this same phenomenon’s regional or spatial dimensions.

OBJECTIVES OF THE SPECIAL ISSUE

Given this lacuna in the existing literature and the paucity of published research on climate change in this and other regional science journals, the objective of the seven papers that together comprise this collection of Spatial Economic Analysis is to provide systematic analyses of some of the key spatial economic impacts of climate change. In determining which of myriad such impacts to focus on, we have been guided by some of the significant findings in the current literature.

For instance, Dale (1997, p. 753) and other researchers have pointed out that ‘humans will change land use, and especially land management, to adjust to climate change and these adaptations will have some ecological effects’. Therefore, the first three of seven papers – by Nicita et al. (2020, in this issue), Engstrom et al. (2020, in this issue), and Estrada et al. (2020, in this issue) – analyse land-use changes, broadly construed, from alternate vantage points. Specifically, Nicita et al. (2020, in this issue) study the relationship between climate, land values and landscape diversity in a Mediterranean region. Engstrom et al. (2020, in this issue) use a bioeconomic lens through which to examine pollination by bees and the optimal provision of ‘semi-natural habitats’ in the Stockholm region. Estrada et al. (2020, in this issue) study how the risks associated with climate change impact both crop yields and agricultural land.

Kirilenko and Sedjo (2007, p. 19697) have argued that ‘[c]hanging temperature and precipitation pattern and increasing concentrations of atmospheric CO2 are likely to drive significant modifications in natural and modified forests’. As such, the fourth and the fifth papers – by Albers et al. (2020, in this issue) and Siebel-McKenna et al. (2020, in this issue) – look at how forests might be protected and managed in the face of climate change. In particular, Albers et al. (2020, in this issue) study how policies that protect certain areas can attenuate some of the deleterious impacts of climate change stemming from forest loss and increased CO2 emissions. Siebel-McKenna et al. (2020, in this issue) analyse how the notion of a carbon price can be used to get forest managers to adopt longer rotation periods which, in turn, lead to higher levels of carbon sequestration in the pertinent ecosystem.

According to Schweikert et al. (2014, p. 306), ‘[c]limate change poses a critical threat to future development, particularly in areas where poverty is widespread and key assets such as infrastructure are underdeveloped for even current needs’. Consistent with this viewpoint, the sixth paper – by Wang et al. (2020, in this issue) – studies how seaports adapt to climate change induced natural disasters. Finally, the seventh paper – by Fouzia et al. (2020, in this issue) – examines how climate change-induced natural disasters influence the labour market in a variety of counties in the United
States. The rationale for this study is provided by Jessoe et al. (2018, p. 230), who use Mexican data and point out that extreme heat increases migration domestically from rural to urban areas and internationally to the US. A medium emissions scenario implies that increases in extreme heat may decrease local employment by up to 1.4% and climate change may increase migration by 1.4%.

With this discussion of our objectives out of the way, we now proceed to comment succinctly on the intellectual contributions of the papers that comprise this collection. To this end, we first concentrate on the three papers that analyse the connections between global warming and changes in land use.

**LAND-USE CHANGES**

The Ricardian approach
Nicita et al. (2020, in this issue) begin their analysis of the connections between land values, climate change and landscape diversity in Sicily (Italy) by first pointing out that farmers in the Mediterranean region in general are likely to be adversely affected by the higher mean temperatures that one can expect from the onset of global warming. That said, how exactly might Mediterranean farmers respond to the expected temperature changes? In addition, might we see changes in ‘agrobiodiversity’ and land returns?

To answer these sorts of questions, the authors conduct their analysis with the so-called ‘Ricardian approach’ made famous by Mendelsohn et al. (1994). This approach uses economic data on the value of land to study how climate in different places influences the net rent or value of farmland. By directly measuring farm prices or revenues, this framework can account for the direct impacts of climate on the yields of different crops as well as the indirect substitution of different inputs, the introduction of different activities, and other possible adaptations to different climates.

Using data for individual farms in Sicily provided by the Italian Farm Accountancy Data Network, the authors first identify a variety of explanatory variables such as farmland value, the elevations of the individual farms the land share that is rented, and the so called Shannon–Wiener index of agrobiodiversity. They then estimate a series of econometric models that yield useful insights into the functioning of Sicilian farms.

Specifically, we learn that there is spatial correlation in the data and that adaptation to climate change by farmers is endogenous. We also learn that the maintenance of agrobiodiversity is important because it positively affects farmland value, provides adaptation and mitigation benefits, and enhances the provision of ecosystem services. Therefore, from a policy perspective, the findings in this paper clearly call for action to preserve and even increase agrobiodiversity because of its numerous salutary impacts on, *inter alia*, the value of farmland.

Pollination and rapeseed oil production
It is well known that healthy ecosystems are resilient in the sense of Holling (1973). In addition, as Perrings (1995) has pointed out, a key value of biodiversity stems from the fact that it promotes an ecosystem’s Holling resilience. Even though these two points are now well understood, Engstrom et al. (2020, in this issue) contend that there is a pressing need to better comprehend the complex interactions between climate, crops and biodiversity.

As such, the authors use a bioeconomic model to analyse the key role played by diverse and wild pollinator bees in enhancing the production of rapeseed oil in the Stockholm region of Sweden. The diverse bees studied include solitary bees and bumble bees. In addition, the authors are keen to assess how changes in the habitats of these wild pollinator bees – what they call semi-natural habitats – along with climate change affect the well-being of the two types of bees. Climate change is important in this setting because it is expected to have dissimilar impacts on the ability of the solitary and the bumble bees to pollinate rapeseed.
To shed light on these sorts of issues, the authors analyse an infinite-horizon, discrete-time, dynamic, stochastic general equilibrium bioeconomic model with three state variables: temperature and two different types of bees. The key task confronting a farmer is to determine the optimal amount of land or semi-natural habitat to set aside and not cultivate. In terms of the model of this paper, this means the farmer first observes the stock of the two types of bees and then ascertains how much land to set aside or leave uncultivated. Put differently, each year’s decision to leave land wild is based on the known stocks of the two types of bees. What is stochastic in the model is the impact that a year’s set-aside decision has on the regeneration of the two bee stocks.

The bioeconomic model yields some interesting conclusions. We learn that except when the number of solitary bees is very low, the optimal amount of semi-natural habitat is negatively related to the current stock of bees. Second, even though bumble bees are the major pollinators relative to solitary bees, solitary bees have a ‘resilience value’—meaning that they contribute to the overall pollination service capacity—that depends on the two bee stocks and is an increasing function of both the mean temperature and the variation in this temperature. Given that very little is now known about the nexuses between temperature and bee population dynamics, from a policy standpoint, this paper is useful because it shows how one might quantify the economic value of biodiversity.

**Assessing impacts on agriculture**

Even though many studies have now examined the impacts of climate change on agriculture, most of these studies focus on state, country or even broader regions. Hence, they ignore the spatial variability in the effects of climate change even though these effects can be large. Given this state of affairs, Estrada et al. (2020, in this issue) build on Blanc (2017) and include ‘crop emulators’ into an integrated assessment model (IAM). The construction of this IAM is complex because it combines elements of statistical and econometric methods, process-based crop models, statistical simulation and an integrated assessment framework. The use of this IAM permits the authors to generate individual and multivariate probabilistic projections and risk metrics that can be used to support the activities of both decision-makers and stakeholders. In addition, the authors also provide a specific application of the so-called Assessment of Impacts and Risks of Climate Change on Agriculture (AIRCCA) simulation model with which they create stochastic impact scenarios and risk metrics at a very fine spatial resolution for rain-fed maize, wheat and rice, which are, arguably, three of the most important global crops.

The detailed empirical analysis conducted by the authors leads to several noteworthy findings. Here are three examples. First, we learn that unabated climate change will significantly affect the present distribution of areas that are suitable for the rain-fed production of the three crops under study. Second, many parts of the world such as northern Africa, the Middle East and the eastern parts of the United States will experience non-trivial declines in crop yields. Finally, although some parts of Europe will see increases in crops yields as a result of climate change, the same cannot be said about other parts such as Portugal and Spain, which are likely to experience declining yields for all crops during the present century.

The AIRCCA model that the authors work with has two key advantages. First, it can readily be used by policy-makers to gauge the impact of climate change on agriculture and on agricultural land in a policy-maker’s chosen region of interest. Second, alternate settings in the model can easily be adjusted by a policy-maker to compare and contrast the implications of alternate climate change scenarios.

**FORESTRY**

**Protecting forest areas**

The degradation of forests contributes not only to forest area loss but the resulting carbon emissions exacerbate the climate change problem. Therefore, policies that protect forest areas ought to
mitigate the climate change problem. Based on this intuition, Albers et al. (2020, in this issue) conduct fieldwork and then analyse the properties of what they call ‘protected area policies’ (PA). Their analysis is guided by the belief that managers can best use their limited enforcement budgets by first comprehending the ways in which villagers make their extraction choices.

The model used by the authors has two types of agents in it. Both types can influence the stock of a specific resource. There is a landscape manager and there are individual villagers who harvest the resource that is subsequently sold at a particular price. The manager can affect the extraction decisions of the villagers by selecting PAs and also by choosing the extent to which these PA designations are enforced. The manager has full information about the villagers, particularly their response to the creation of PAs. An individual villager knows the location of the PAs, the likelihood of getting caught if he illegally extracts from a PA and the fact that other villagers will be making similar spatially explicit extraction choices. In each time period, an individual villager chooses how to allocate his time to resource extraction across a spatial landscape and to wage labour in his village. After an extraction period, the resource grows via an exogenously given density dependent growth process. The equilibrium of interest in this strategic interaction or game between the manager and the individual villagers is a spatial Nash equilibrium.

Application of the model shows that how much additional carbon storage a network of PAs gives rise to depends greatly on the extent to which this network is able to change the spatial decisions of the individual extractors. Second, the optimal configurations and the enforcement of created PAs differs between managers who concentrate on PAs specifically versus managers who concentrate on the entire landscape. Finally, with many nations and communities now formulating REDD+ policies based on the enforcement of PAs, the analysis in this paper shows that by paying attention to the spatial decisions of extractors, one can gain insights into how a policy-maker might increase the avoided carbon emissions produced by REDD funding.

Managing forests differently

Forests are standardly considered to be carbon sinks. Hence, forest managers can take actions to increase the capability of storing carbon by practising enhanced reforestation and afforestation and also by either avoiding or delaying deforestation. Also, if the goal of forest management is to reduce atmospheric CO$_2$ concentrations, then it is essential for managers to pay attention to random timber and carbon prices and the carbon fluxes arising from natural disturbances such as wildfires.

With this background, Siebel-McKenna et al. (2020, in this issue) use a stochastic dynamic programming approach to determine the optimal decisions of a forest manager who faces probabilistic tree growth and alternate specifications of wildfire risk over a range of carbon prices. Specifically, this manager maximizes the expected net present value of an even-aged stand by waiting to harvest until the optimal rotation age is reached. This maximization problem is stochastic because, following Van Kooten et al. (1992), the growth of a forest stand is represented by Markovian transition probability matrices. The region studied is the Quesnel Timber Supply Area (QTSA) in British Columbia, Canada.

Application of the model demonstrates that when one accounts for carbon prices in the forest management problem, the optimal rotation periods become longer. In contrast, accounting for natural disturbances such as wildfires reduces the same optimal rotation period and this reduction can be interpreted as a safeguard against the increased risk. We also learn that as carbon prices rise, the amount of carbon sequestered in living and dead biomass first increases, but then plateaus and that the amount of carbon stored in harvested wood products decreases. Finally, if, as a result of climate change, natural disturbances increase over time then this feature will make it more difficult for national governments to use forest management to be in compliance with IEAs such as the 2015 Paris Agreement.
INFRASTRUCTURE

It is now well known (Min et al., 2011) that the number and the strength of climate change-induced natural disasters are likely to increase over time. Seaports are very vulnerable to certain kinds of natural disasters such as hurricanes, strong winds and heavy rainfall. Therefore, if seaports are to be resilient in the sense that they are able to function under a wide range of potential natural disasters, then they will need to adapt efficaciously to such disasters.

Wang et al. (2020, in this issue) note that even though the above point has been recognized, there is very little analytical research on the adaptive behaviour of seaports. In addition, the few existing studies on this topic have paid no attention to how the market structure of the terminal operator companies (TOCs) and the kind of competition or cooperation they engage in affects the incentives to adapt to the greater likelihood of natural disasters. To fill this lacuna in the literature, the authors analyse a model of a region with two seaports that interact – compete or cooperate – with each other. Each seaport consists of an upstream port authority (or landlord) and several downstream TOCs (the tenants) that operate in an oligopolistic market structure. The two seaports are spatially distinct, and they are subject to climate change-induced natural disasters. The authors seek to answer the following two questions: First, how does competition or cooperation by the TOCs in the same port (intra-port) and competition or cooperation by them across the two ports (inter-port) affect the adaptation investments that are undertaken? Second, does the market structure within which the TOCs operate have any effect on the disaster preparedness of the two seaports?

Given a particular seaport, the authors find that climate change induced adaptation is an increasing (decreasing) function of the number of TOCs in this (the other) seaport. Second, common ownership of the various TOCs across the two seaports decreases adaptation to climate change. Finally, if the likelihood of disasters affecting the two seaports under study is asymmetric, then there is greater adaptation by the seaport that expects to be hit by a disaster with a higher probability. The generality of these findings can be ascertained by examining the case where adaptation is undertaken not just by the port authorities but also by the individual TOCs.

LOCAL LABOUR MARKET EFFECTS

As our discussion of the various papers comprising this collection shows, the climate change phenomenon has had and is likely to continue to have powerful economic impacts over space. That said, Fouzia et al. (2020, in this issue) make three useful points. First, they contend that we still know relatively little about the many ways in which climate change-induced natural disasters affect local labour markets. Second, they point out that even though some existing studies provide information about the ‘employment effects’ of natural disasters, this is not enough. In addition to the employment effects, we also need to learn about the pertinent ‘wage effects’. Third, they remind us that it is important to comprehend the mechanisms that give rise to the varied employment effects of natural disasters.

To this end, the authors use US county-level data about climate change-induced disasters that comes from the Spatial Hazard Events and Losses Database for the U.S. and investigate the impacts of eight different kinds of disasters on local labour markets. Because, for most disasters, the temporal persistence and the related spatial spillover effects are largely unknown, these authors conduct their econometric analysis with a spatial Durbin error model (SDEM). This modelling strategy allows them to account for the fact that the economies of counties that are adversely impacted by a natural disaster are also impacted by what happens in neighbouring counties.

The findings obtained provide ample food for thought. Here are four examples. First, some disasters such as heat and hurricanes lead to positive total impacts on both employment and
wages, but other disasters such as tornados and severe storms have the opposite effects on employment and wages. Second, depending on the disaster being considered, the past effects can either strengthen or weaken the direct or immediate effects. Third, the impacts of the different types of disasters that are studied are typically transmitted over both time and space and hence it would be manifestly unwise to ignore either of these two categories of spillovers. Finally, even though it is difficult in practice to disentangle the underlying demand and/or supply shifts that cause the observed changes in employment and wages, it is sometimes possible to use socioeconomic indicators to identify the correlation between the disaster generated impacts that we see and demand and/or supply shifts.

CONCLUSIONS

We have now set the stage for this issue by first pointing to the lacunae that exist in the current literature on the spatial economic impacts of climate change and then by briefly discussing the contributions of the individual papers. We believe that each contribution expands the current frontier of knowledge about the connections between climate change and (1) land-use changes, (2) forestry, (3) infrastructure and (4) local labour markets. As such, this collection ought to be of great interest to all readers interested in learning more about the myriad ways in which the phenomenon of climate change and spatial impacts are linked. In addition, the research described here should stimulate research into the connections between climate change and related spatial topics such as migration (e.g., Gray & Wise, 2016), the relocation of firms (e.g., Linnenluecke et al., 2011), and the spread of diseases (e.g., Jaya et al., 2017; Jaya & Folmer, 2020a, 2020b).

NOTES

1 Throughout, we use the terms ‘climate change’ and ‘global warming’ interchangeably.
3 To the best of our knowledge, only two published papers in this journal have something to do with climate change. The first, by Temurshoev and Oosterhaven (2014), looks at CO2 emissions in passing, but their main purpose is to study the nature of sectoral linkages in an economy. The second, by Dallerba and Dominguez (2016), is about how climate change affects farmland values across the south-western United States. As such, it complements the analysis conducted in the three papers in this collection that analyse the nexuses between climate change and changes in land use.
5 Some land is set aside and not cultivated because it provides the habitat for the two types of bees being studied.
6 REDD refers to reducing emissions from forest degradation and deforestation.
7 See Kahn (2016) for a general discussion of the importance of adaptation in the context of climate change.

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