Climate change adaptation based on computable general equilibrium models – a systematic review

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Abstract

Purpose – This study aims to identify the current state of the art and the gaps in the application of computable general equilibrium (CGE) models on studying climate change adaptation.

Design/methodology/approach – A systematic review is conducted to select, classify and analyze relevant studies from two databases of Web of Science and Scopus.

Findings – Totally, 170 articles based on selected keywords were found from both databases, where 56 articles were duplicates. The authors further excluded 17 articles owing to preliminary exclusion criteria. Hence, 97 papers were selected for full-text review and more detailed assessment. Only a few of the studies explicitly have addressed the role of autonomous adaptation embodied in the CGE models. Over one-third of the studies have focused on planned adaptation without explicitly mentioning autonomous adaptation. Agriculture was the most addressed sector, and country-level models are the most adopted. Only one article has focused on South America.

Research limitations/implications – The review suggests that autonomous adaptation embodied in CGE models was not well addressed in the literature. As the limited studies have shown that autonomous adaptation can dramatically mitigate direct climate change impacts, further studies are needed to examine the importance of the autonomous adaptation for better understanding of climate change impacts. Furthermore, CGE models can provide a joint assessment considering both mitigation and adaptation strategies and management measures as such models have also been widely used to address effects of mitigation measures in the literature.

Originality/value – The studies on climate change adaptation based on CGE models have been systematically reviewed, and state-of-the-art knowledge and research gaps have been identified.

Keywords Adaptation, Climate change, Systematic review, Economic impact, CGE model

Paper type Literature review

1. Introduction

People and societies will have to deal with climate change both by keeping the drivers of climate change under control and by handling the impacts of the change in weather

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conditions. Most attention, also among researchers, has been on the control of the drivers of climate change, particularly greenhouse gas emissions. However, concerns about impacts and adaptation have grown over the past 15 years. This is partly because it has been realized that the climate will change notably in many places, despite radical efforts to mitigate climate change. In addition, there are already observations of changes that can be related to the ongoing increase in global mean temperature (Masson-Delmotte *et al.*, 2021).

The relevance of considering the implications of alternative ways to deal with these two challenges depends on widely different social and economic aspects. Effects of mitigation must be evaluated in a global perspective. Strong measures taken in one country or among people, and companies within countries have little or no effect unless they are coordinated with initiatives in other countries. Adaptation depends on what happens where, and how to adapt depends on who you are. A given change in climate will affect the life of people and businesses in different ways, depending on what opportunities they have. The different contexts in which the challenges that follow in the wake of climate change are demonstrated by the saying that "mitigation is global, while adaptation is local" (Klein *et al.*, 2007).

Most of the research on adaptation therefore focuses on local conditions (Klein *et al.*, 2007). Studies address opportunities and challenges to people, companies and local authorities in selected areas, based on relatively detailed information on changes in weather patterns and their impacts on the natural environment. The studies provide support to various groups of people, managers of firms and local authorities in dealing with the challenges that follow.

Despite the apparent relevance of focusing on local conditions, adaptation matters also to the development of national policies. The possibility for large-scale impacts and the need to prepare for unexpected events indicate that general regulations and measures may involve considerable socioeconomic benefits. Hence, it is essential to make sure that people, managers of firms and communities on local levels have the right incentives to include expected impacts on the society when they prepare for expected changes in their own surroundings. Support to the national authorities requires information about the entire society, which encompasses possible impacts on the interdependencies between people and economic actors.

Impacts and adaptation within agriculture, for example, must be considered beyond questions about what happens to the productivity of land and crop yields and what farmers can do to prepare for and limit losses if the climate changes. Their opportunities depend also on what happens to farmers both in their own and in foreign countries, as the markets they operate in will be affected, and provide new opportunities or limit the markets they operate within from the outset. Impacts and adaptation among farmers in poor countries, whose livelihood depend on a combination of subsistence farming and monetary income from different activities, depend critically on how their monetary income will be affected, which again must be considered in a broader context than just what happens to their own farm. Computable general equilibrium (CGE) models have been one of the best tools to assess impacts and adaptation considering interactions among sectors and regions. Hence, this paper reviews 97 studies that apply CGE models for the purpose of analyzing climate change adaptation. As impact and adaptation are likely local at sectoral or regional level, this review extracts information on sectors and regions, and divides the findings according to journal disciplines, publishing years and types of adaptation measures.

To facilitate the understanding of the mechanism of CGE models in a study on adaptation to climate change impact, the next section gives an overview of how CGE models describe national economies, the underlying data and how impacts of climate change can be represented. Then follows Section 3 describing the methodology used to select relevant studies for this review. Section 4 analyzes the selected articles from five aspects: disciplines

of journals, publishing years, focused sectors, study regions and type of adaptation measures. Section 5 concludes.

2. Impacts and adaptation addressed by computable general equilibrium models

CGE models can be considered as a generalization of the standard theory of market equilibrium (Burfisher, 2021). A typical CGE model describes all economic activities in a country, a world region or the entire world using data from national accounts. Such a model can simulate how markets respond to changes in technologies, in preferences and/or in the availability of labor, capital and natural resources, with the resulting impacts on the production and consumption of selected goods and services. Impacts of climate change can be represented by how climate change affects the production and consumption of goods and services (Aaheim and Schjolden, 2004). The initial impact appears as a change in the supply or the demand of certain good or service caused by climate change. A lower supply of a good, for example, will lead to a higher price, which again spurs substitution with other goods and services. Then, prices and quantities of these goods will also change, and in the end, the initial impact propagates to the entire economy.

2.1 The structure of computable general equilibrium models and integration of climate impacts

In CGE models, the production of goods and services in each economic sector is generated by input of primary factors (including labor, capital and natural resources) and intermediate factors delivered from other sectors (Ten Raa, 2006). The total demand for the output in each sector thereby consists of demand from other economic sectors and demand from consumers and investors. Technologies are represented by production functions that describe the relationship between the use of different input factors and output in each sector (Burfisher, 2021). Consumers' demand is described by relationships between the consumption of goods and services and welfare. The demand from investors depends partly on assumed depreciation of capital and partly on investments needed to achieve economic growth, which are often determined from scenarios. The models derive the demand for goods and services from economic sectors and from consumers and investors under the assumption that producers maximize profits and consumers maximize total welfare under given prices (Burfisher, 2021). The supply then follows from the demanded input of production factors by sector. Finally, market prices are determined by market equilibrium, where the supply equals the demand for goods and services from each sector.

Figure 1 illustrates the main relationships and flows in CGE models (Aaheim *et al.*, 2018). Data on input by sector are shown along the vertical axes for each sector, and for the final deliveries. The horizontal axis thereby shows the demand in each sector for deliveries from other sectors and from consumption and investments. The three lower lines show input of the primary production factors, labor, capital and natural resources by sector. The input of primary factors generates value added by sector, which sums up to the total income (GDP). The basic versions of these models assume all the income equals the total expenditures, which generate the demand for goods and services.

The green and pink arrows summarize the supply and demand by sector, from which supply and demand functions are estimated. Changes in the productivity within production sectors or in the preferences among consumers or investors will lead to shifts in the demand functions. A change of technology in a production sector, for example, leads to a shift in the demand for input factors to this sector under current prices. Some sectors must deliver more, and other sectors less. This leads to a change in the composite of output from these sectors,

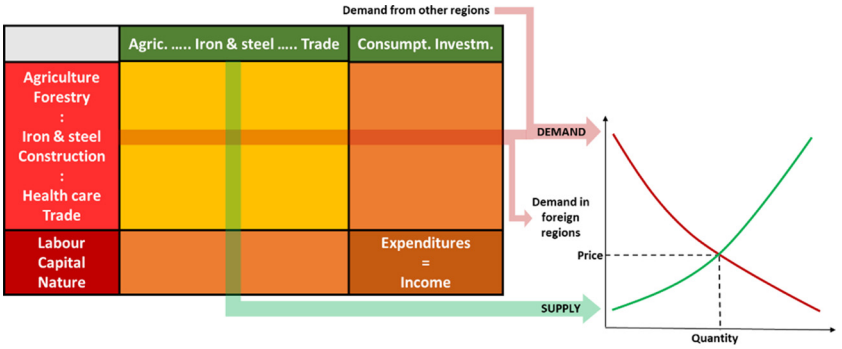

Figure 1.
The structure of CGE models

Source: Modified from Figure 1.1 in Aaheim *et al.* (2018)

which affect the prices, meaning that all who demand goods and services from these sectors are faced with a change in prices. This affects the prices of these goods and services as well. In principle, the initial change in technology within one sector thereby propagates to the entire economy.

Impacts of climate change can be represented by assessments of how primary production factors, technologies and preferences are affected (Aaheim *et al.*, 2012; Dellink *et al.*, 2019). In agriculture, for example, changing climate will lead to a change in the productivity of land (Wei and Aaheim, 2021), health effects will have an impact on the productivity of labor (Orlov *et al.*, 2020) and extreme events will cause damages to the capital stock (Carleton and Hsiang, 2016). There may also be direct impacts on the demand for goods and services. Energy demand will change with changes in temperature (Gonseth *et al.*, 2017), impacts on tourism will affect the demand for transport and hotels (Gonseth and Vielle, 2019) and health effects affect the demand for health services (Ciscar *et al.*, 2011).

2.2 Autonomous and planned adaptation

Studies of adaptation often distinguish between autonomous adaptation and planned adaptation (IPCC, 2007). With reference to the modeling described above, planned adaptation can be defined by actions taken to prepare for expected changes in future climate or to adapt to experiences from observed climatic changes. Autonomous adaptation covers responses to the economic impacts of climate change on the supply and demand for goods and services, and the resulting market effects. When applied as definitions in a broader academic context, the difference is not entirely clear, however, as it depends on the approach taken to explain behavior within a given academic discipline. What may be understood as ordinary behavior in one academic approach, and thereby categorized as autonomous adaptation, may require a specification of expectations about future climate to be explained in another academic approach. Then, the choice appears as planned adaptation.

Being based on the economic theory of market equilibrium, the distinction between planned and autonomous adaptation may seem less problematic. Still, the distinction is not crystal clear, because different economic models represent impacts of climate change in different ways. What can be explained as autonomous adaptation in one model may have to be addressed as planned adaptation in another model. Many economic models apply assessments of costs expressed by the impact on value added to represent impacts of climate change (Nordhaus, 1993). Then, the impacts of substitution, for example between labor,

capital and natural resources, due to a change in the impact on one or more input factors must be added as an external change in the demand for goods and services, which appears as planned adaptation according to the definition above. If estimates or sub-models of impacts are attached to specific economic activities, these impacts will be covered by autonomous adaptation.

The main contribution from studies of adaptation by CGE models is, however, that they add a socio-economic dimension to understand how adaptation affects social and economic consequences of climate change. When people, business managers and public authorities adapt to local impacts, the interdependencies between activities across communities and countries will be affected. The impacts on these interactions may be large, but there has been relatively little attention to them as shown in Section 4. Most studies of adaptation address challenges to people in communities of today if faced with climatic changes expected to appear far into the future (IPCC, 2022).

Local studies play an important role to understand what challenges climate change imply and what groups of people, business managers and local authorities can do to deal with them. Lessons from these studies provide a basis for identifying opportunities for adaption in future societies. They thereby constitute a first step in what national authorities need to know for their purposes. To them, policies related to climate impacts and adaptation is a part of a national policy, however, and their responsibility is to develop strategies and select measures that apply on the national level. They must include adaptation in their evaluations of mitigation and consider climate policy in the context of other political issues. In doing so, it is necessary to understand how interactions between communities and countries will affect the impacts of climate change and thereby challenges related to adaptation, also on local levels.

Integrating lessons from local studies in CGE models allows for projecting challenges to adaptation under future pathways. Addressing adaptation by CGE models thereby closes a gap between evaluations of mitigation and evaluations of impacts and adaptation, which is often considered independent of each other in climate research as well as in policy making.

3. Methodology and data

A systematic literature review is an approach widely used across disciplines by adopting systematic methods to identify, synthesize and critically analyze relevant studies focusing on a given topic or research question (Gough *et al.*, 2012; Kitchenham, 2004; Waddington *et al.*, 2012). A previous study has adopted a systematic review to identify and summarize CGE model-based studies related to climate change mitigation policy (Babatunde *et al.*, 2017). As CGE models are also increasingly used to study issues related to climate change adaptation as presented above in Section 2, this study conducts a systematic literature review of CGE-based studies on climate change adaptation considering its advantages compared to the traditional literature reviews: well-defined research questions, standard methods and criteria for searching and including relevant studies and critical analysis (Berrang-Ford *et al.*, 2015; White and Schmidt, 2005).

To establish a database of previous studies on climate change adaptation based on CGE models, a literature search was conducted focusing on two well-known databases: Scopus (www.scopus.com) and Web of Science (www.webofscience.com). The following strings of keywords were used for searching the topic without restrictions of publishing years in both databases on August 2, 2021:

["adaptation" AND "climate" AND ("computable general equilibrium" OR "CGE")].

We have chosen these limited keywords to obtain any possible studies relevant to climate change adaptation based on CGE models. We believe that any studies that do not

mention these keywords jointly must be irrelevant to our purpose, or only marginally relevant.

We obtained 75 articles from the Web of Science and 95 articles from Scopus. Among all the articles, there were 56 articles in both databases. Hence, we got 114 articles for further analysis. We then refined the results to exclude papers that satisfy at least one of the three conditions below:

(1) A CGE model is not the key analysis approach.

(2) The adaptation to climate change is not one of the key research questions.

(3) An article is a literature review article.

Hence, another 17 articles were removed from the list, and we ended up with 97 articles.

Notice that this is not a complete list as we did not include the articles published after August 2, 2021. In addition, some articles were not included as neither "computable general equilibrium" nor "CGE" has been mentioned in its title, abstract and keywords, although some other alternatives like "macroeconomic general equilibrium" have been mentioned in its abstract (Aaheim *et al.*, 2012). Even though, we believe our review covers most representative studies in the topic.

We then reviewed the selected 97 articles in more detail to extract information about authors, journal names, publication years, focused sectors and locations and types of adaptations (planned or autonomous). This information is further analyzed in the next section to identify whether more attention has been paid on the topic over time, which disciplines have been covered, which sectors and regions have been studies. Particularly, we have a close examination of how climate change adaptation has been studied in these articles and summarized the key findings on adaptation of these articles.

4. Review findings and discussion

4.1 Temporal distribution of the computable general equilibrium studies

The CGE-based studies on adaptation appeared about ten years later compared to the CGE-based studies on mitigation (Babatunde *et al.*, 2017). As shown in Figure 2, the first article in the list was published as a conference article by Smajgl (2007) assessing policy options in response to climate change impact on water quantity and quality. This is followed by

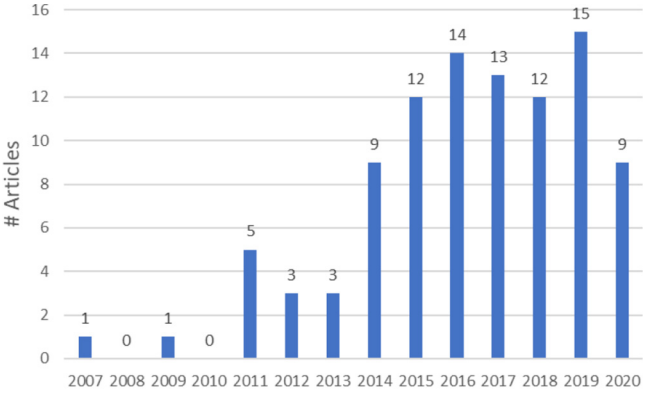

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Figure 2.
Distribution of years of the 97 CGE-based articles on adaptation

Boyd and Ibarrarán (2009) studying planned adaptation measures to a drought in Mexico, published in *Environment and Development Economics*. The next five articles then appeared in 2011. After three articles in each of 2012 and 2013, the yearly published articles during 2014–2020 are rather stable, ranging from 9 to 15. It seems that the CGE-based studies on adaptation are still underdeveloped, and we would expect more studies will come in near future, as a CGE model is one of the best tools for integrated analysis simultaneously considering mitigation, impact and adaptation in the climate change science.

4.2 Computable general equilibrium studies by journal discipline

The 97 research articles were published in 63 journals. We further classify the 63 journals into different disciplines. If a journal title includes the word "Economics" or "Economic," then we classified it as a journal in the "Economics" discipline, although words of other disciplines may appear in its title, e.g. the journals "Agricultural Economics," "Climate Change Economics," "Environmental and Resource Economics" and "Water Resources and Economics." Figure 3 shows the distribution of disciplines of the 63 journals. Nearly 40% of the articles (37) were published in economics journals. Around 30% of the articles were published in environmental (17) and interdisciplinary (13) journals. It is also natural that around 15% of the articles (16) were published in climate journals as the topic is about climate change adaptation. The other articles were published scarcely in other disciplinary journals of agriculture, food, water and policy.

4.3 Regions focused by the computable general equilibrium studies

As shown in Figure 4, we first clarified the studies to be at city, country, regional and global level (a), then at the continental level (b) and finally, show the distribution of the 53 country-level studies (c). Over 50% of all the studies are at the country level, and only four articles at the city (or subregion within a country) level (Fan and Davlasheridze, 2019; Gertz *et al.*, 2019; Hirte *et al.*, 2018; Smajgl, 2007). Global studies account for 25% of all the studies, where the world can be divided into several regions (or countries). More than 15% of the studies focus on one region, including two or more countries, e.g. Europe, South Asia and Mediterranean economies.

At the continent level, besides studies involving the global economy, around 20% of the 97 articles focusing on a place (city, country or region) located in each of three continents:

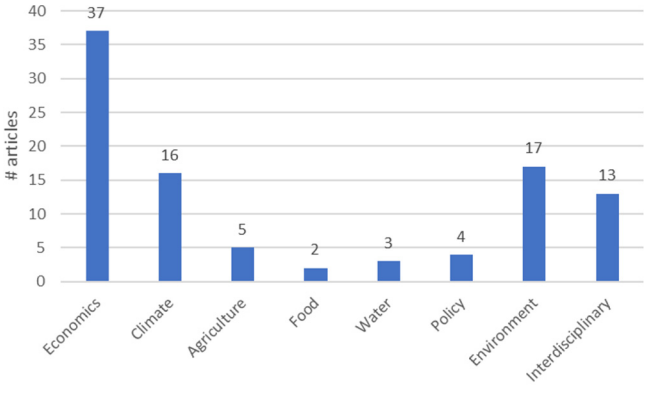

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Figure 3.
Distribution of journals where the 97 research articles on CGE analysis of climate change adaptation were published

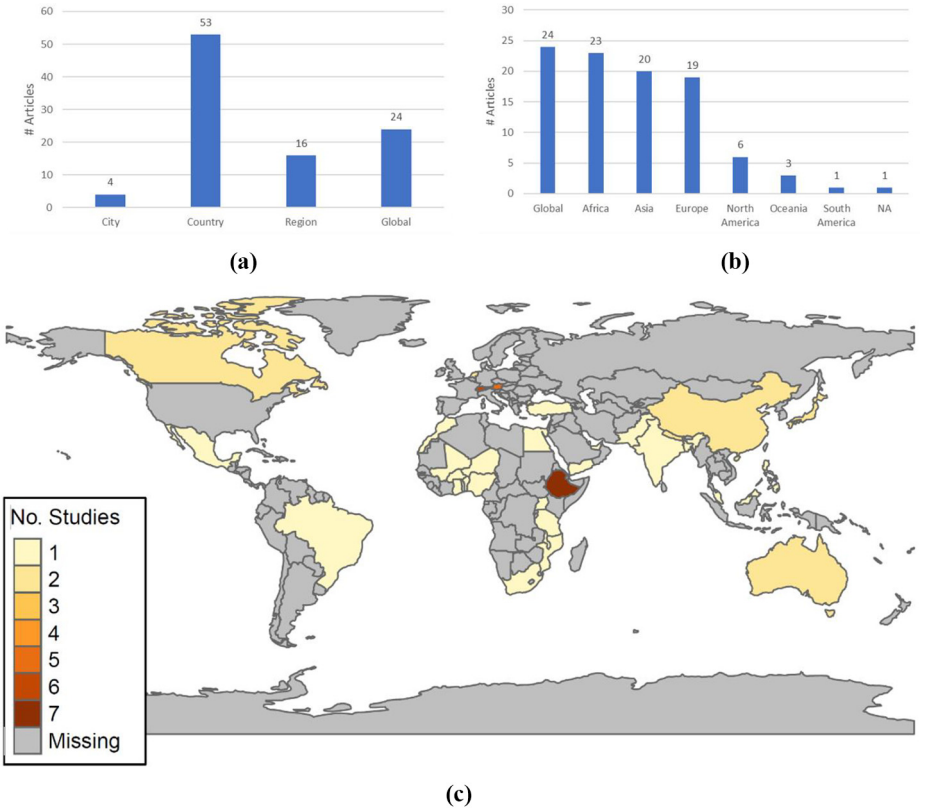


Figure 4.
Geographic distribution of the 97 articles on CGE-based studies on adaptation

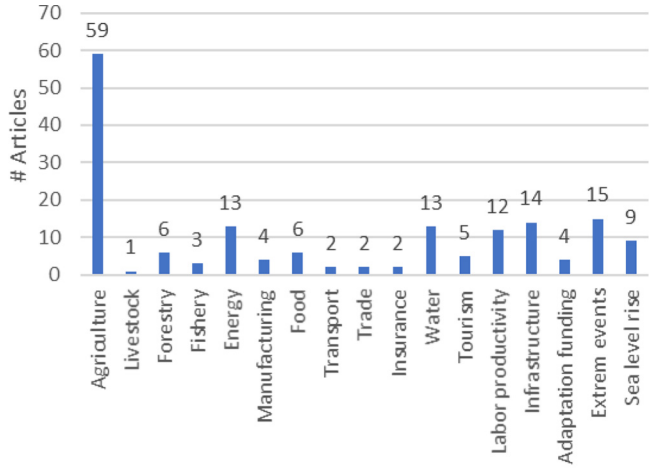
Notes: (a) From city to global; (b) by continent; (c) for the 53 countrylevel studies
Source: Authors' own illustration

Africa, Asia and Europe. Only three articles focused on a place located in Oceania, and one article on Brazil in South America (Nazareth *et al.*, 2020). The remaining six articles focused on North America.

If we closely see the distribution of the country-level studies [Figure 4(c)], we found that seven studies on Ethiopia, six on Switzerland and five on Austria. Only one or two studies were found for the other countries such as Brazil, China, Canada, India, Japan and South Africa. Surprisingly, none of the country-level studies has focused on the USA or Russia, both of which are critical partners for successful climate actions. This is different from CGE studies on mitigation, where considerable share of the studies focusing on USA and China, while none on Brazil, Russia and Africa (Babatunde *et al.*, 2017).

4.4 Sectors focused by the computable general equilibrium studies

Figure 5 shows the sectoral distribution of the CGE-based studies on adaptation. As a study can simultaneously focus on more than one sectors, the total amount of the sectoral studies is more than 97 in Figure 2. Among the 97 studies, nearly 60 studies have agriculture as one of their focused sectors. Around 14 studies for each of the sectors, including energy, water,



Source: Authors' own illustration

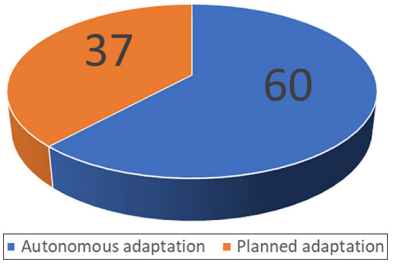
Figure 5.
Sectoral distribution of the 97 CGE-based studies on adaptation

labor productivity, infrastructure and extreme events. Nine studies focused on sear level rise, six on each of forestry and food and five on tourism. Less than five studies have focused on each of the other sectors, including livestock, fishery, manufacturing, transport, trade, insurance and adaptation funding. On the contrary, the most focused sector of the CGE studies on mitigation is energy, and much less on other sectors, including agriculture (Babatunde *et al.*, 2017).

4.5 How adaptation is addressed in the computable general equilibrium studies

As presented in Section 2, autonomous adaptation embodied in a CGE model must be involved in an adaptation study based on the CGE model, although many studies have not explicitly mentioned the term "autonomous adaptation" in their CGE simulations. Hence, we assume all the 97 articles have considered autonomous adaptation embodied in the CGE models. In addition to the autonomous adaptation, more than one third of the 97 articles have considered planned adaptation measures (Figure 6).

Only a few of the studies have explicitly mentioned the term "autonomous adaptation" in their abstracts (Hasegawa *et al.*, 2014, 2016; Mitter *et al.*, 2015; Wei *et al.*, 2017). In several other studies, similar terms to the effect of the embodied autonomous adaptation include



Source: Authors' own illustration

Figure 6.
The distribution of CGE studies on autonomous and planned adaptation

rebound effect (Gonseth *et al.*, 2017; Labriet *et al.*, 2015), indirect impact (Chalise *et al.*, 2017; Koopman *et al.*, 2015; Schönhart *et al.*, 2013), market adaptation (Koopman *et al.*, 2015), carbon leakage (Gonzalez-Eguino *et al.*, 2012), economy-wide effect (Chalise and Naranpanawa, 2016; Kahsay *et al.*, 2017; Nazareth *et al.*, 2020; Steininger *et al.*, 2016; Teotonio *et al.*, 2020; Yalew *et al.*, 2018), macroeconomic impact (Labriet *et al.*, 2015; Roson and Damania, 2017; Teotonio *et al.*, 2020) and effect of sectoral interlinkages (Khan *et al.*, 2020; Steininger *et al.*, 2016).

Among these studies, only three studies have explicitly compared climate change impact with and without the autonomous adaptation, and concluded that autonomous adaptation can considerably reduce the climate change impacts focused by these studies. Koopman *et al.* (2015) concluded that autonomous adaptation could lower considerably the economic impacts on agriculture caused by climate change via water availability for irrigation in the Rhine and Meuse river basin regions. Gonseth *et al.* (2017) showed that fossil energy consumption for heating and cooling caused by climate change could decrease only by 2.7% with autonomous adaptation (or rebound effects) rather than by 4.3% in Switzerland. Wei *et al.* (2017) showed that the losses of maize harvest caused by extreme climate events could be reduced from 4% to 1% of the reference level in China.

Among the studies additionally focusing on planned adaptation, the planned adaptation measures examined cover measures in water allocation (Koopman *et al.*, 2017; Smajgl, 2007), agriculture, forestry (Boyd and Ibarrarán, 2009; Ochuodho *et al.*, 2012), fishery (Fathelrahman *et al.*, 2018; Vista, 2014), energy (Boyd and Ibarrarán, 2009; Robinson *et al.*, 2012), transportation (Arndt *et al.*, 2015; Arndt *et al.*, 2011; Robinson *et al.*, 2012), investments and funding, trade liberalization (Ouraich *et al.*, 2019) and ski industry (Gonseth and Vielle, 2019).

The examined adaptation measures in agriculture include improving irrigation and drainage system (Bosello *et al.*, 2018; Calzadilla *et al.*, 2013, 2014; Komarek *et al.*, 2019; Montaud *et al.*, 2017; Robinson *et al.*, 2012; Zeshan and Ko, 2019; Zeshan and Shakeel, 2020; Zidouemba, 2017), improving drought early warning systems (Montaud *et al.*, 2017), adoption of high temperature-tolerant rice varieties (Akune *et al.*, 2015) and adoption of drought-tolerant crop varieties (Montaud *et al.*, 2017), relocating cotton production (Mushtaq *et al.*, 2015), adopting a rice-sugarcane rotation and displacement of sugar (Mushtaq, 2016), adopting climate-smart agriculture and doubling fertilizer use (Komarek *et al.*, 2019).

The examined investments and funding for adaptation include agricultural sector investments (Arndt *et al.*, 2015, 2011; Bosello *et al.*, 2018; Calzadilla *et al.*, 2013, 2014; Elshennawy *et al.*, 2016; Robinson *et al.*, 2012; Zidouemba, 2017), funding of adaptation in developing regions (Ouraich and Tyner, 2018; Schenker and Stephan, 2014), coastal protection investments (Elshennawy *et al.*, 2016; Parrado *et al.*, 2020; Withey *et al.*, 2016), decrease in investments in risky areas (Husby *et al.*, 2016), utilization of insurance and catastrophic bonds (Thirawat *et al.*, 2017), public investments in adaptation (Bachner *et al.*, 2019; Hirte *et al.*, 2018; Hoffmann, 2019; Hoffmann and Stephan, 2018) and adaptation measure of an artificial beach enhancement (Nakajima *et al.*, 2020).

Many of these studies conclude that the introduced planned adaptation measures can mitigate the negative impact of climate change at low cost (Hoffmann, 2019; Robinson *et al.*, 2012; Zeshan and Ko, 2019; Zeshan and Shakeel, 2020) or receive net benefits (Calzadilla *et al.*, 2014; Nakajima *et al.*, 2020; Schenker and Stephan, 2014). Some studies point out that the examined adaptation measures may not be sufficient to solve the problem although helpful (Akune *et al.*, 2015; Arndt *et al.*, 2015; Boyd and Ibarrarán, 2009; Elshennawy *et al.*, 2016; Ouraich *et al.*, 2019; Zidouemba, 2017). Certain adaptation measures may only marginally mitigate climate change impact (Ouraich and Tyner, 2018). It has warned that certain adaptation measures may not be driven by existing market (Mushtaq *et al.*, 2015).

None of the 35 studies focused on planned adaptation has explicitly claimed autonomous adaptation embodied in a CGE model. Several studies have highlighted the importance of considering the effect of autonomous adaptation embodied in a CGE model although without explicit mentioning. For example, by considering the effect of the autonomous adaptation, certain adaptation measures lead to a net benefit for an economy although suffer losses at a sectoral/local level (Bachner, 2017; Bachner *et al.*, 2019) and deficit spending on adaptation might turn out to sustain public finance (Parrado *et al.*, 2020).

4.6 Discussion

The reviewed studies have typically focused on adaptation measures at the country level. Assessments of impacts and adaptation by CGE models address the impacts on social and natural constraints assumed to be basic for decision-making related to economic decisions and show how these impacts affect all economic activities in a country. The models are based on aggregated data on sectoral level from national accounts and provide annual data on the national level. Regional variations, differences within sectors and variations during the year are hidden behind these aggregates, and the linkages between the micro levels and these aggregates are not transparent. With these weaknesses, to the extent that adaptation is considered a local issue, it may seem meaningless to apply these models to study adaptation.

However, the literature indicates clearly that the price effects of impacts of climate change are likely to be significant (Wei and Aaheim, 2021; Zhang *et al.*, 2022). At the same time, prices are also a main driver behind autonomous adaptation among people, in businesses and within local administrative institutions. This may be considered as a main argument for developing CGE models further to address adaptation.

Then, a main challenge is to develop approaches to link determinants of prices from annual, national data to data on impacts and adaptation from local studies and to improve the knowledge on how prices affect the behavior of economic agents on the local level. This is not addressed explicitly in any of the studies reviewed in this survey. However, the specifications of behavior among individuals and economic agents and their relationships to the environment, including nature, make CGE models useful for this purpose.

On the other hand, when considered as a national concern, CGE models provide assessments of how impacts and adaptation will affect figures in the national accounts, which national authorities use in their evaluations of the state of the economy. The models show how and to what extent climatic changes are expected to affect the economic activity in a country, and what implications adaptation will have. As this will depend on how the markets respond to these changes, CGE models also provide information on the local level, which cannot be assessed by focusing entirely on local communities. There is a need to better understand how impacts on the micro level affect information used to evaluate indicators on the national level and vice versa. The theoretical framework underlying the CGE models provide a tool for doing so, and to identify knowledge gaps in combining local and national policies with the aim to limit the negative impacts expected to occur in the wake of climate change.

5. Conclusions

This study adopted a systematic review and selected 97 studies on climate change adaptation based on CGE models for analysis. Our review shows that the topic has attracted more attention in recent years, and it is expected that more CGE studies on adaptation in the future. The expectation is based on the fact that the CGE studies on adaptation have been published in journals of broad academic disciplines, which is also indicating the potential of CGE models to integrate knowledge from various disciplines. In addition, the review shows

that CGE models can be used to address adaptation measures in many sectors such as agriculture, energy, investments and funding, also indicating a CGE model can be used to assess the integrated effects of adaptation measures in several sectors, rather than one sector. On the other hand, most of the reviewed studies have focused on agriculture, indicating potential research gaps on addressing adaptation measures in other sectors.

The review suggests that autonomous adaptation embodied in CGE models was not well addressed in the literature. As the limited studies have shown that autonomous adaptation can dramatically mitigate direct climate change impacts, further studies are needed to examine the importance of the autonomous adaptation for better understanding of climate change impacts.

Although climate change adaptation studies are typically local, the adaptation studies based on CGE models are dominated by country level and more aggregated regional or even global level. Considering the wide adaptation of CGE models in mitigation studies, a global CGE model can be taken one of the proper tools to integrate the joint effects of mitigation policy and adaptation measures in response to climate change impact. Comprehensive analysis of such studies would provide better knowledge to understand the interactions of climate change impact, adaptation and mitigation strategies and management.

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