Introduction

Since climate change has been recognized as a dominant issue for world economy and policy, resources have been looked for financing mitigation as well as adaptation. Logically allocation criteria should be different for mitigation and adaptation. As for adaptation, the criteria should reflect the need of the countries and their capacity to effectively use the resources. The same issue is still highly debated for the criteria of development aid allocation. With regard to the adaptation purpose, the country specific vulnerability to climate change could be considered as one of the most relevant criteria for the allocation of the resources between developing countries. For that purpose, an appropriate indicator of vulnerability to climate change available for all the countries concerned is needed.

There is indeed a huge literature related to vulnerability to climate change, for instances: Global monitoring report of World Bank (2008–chapter 6 and 7), Fourth Assessment Report of IPCC (2007) Climate action UNEP (2010). However it is more focused on particular aspects of this vulnerability than on the search of a synthetic index. And when a synthetic view is proposed, it considers vulnerability in all its components, including the resilience, i.e. the country capacity to cope with the shocks resulting from climate change. If resources for adaptation have to be allocated as a function of the vulnerability to climate change, the vulnerability to be considered is the vulnerability that does not depend on the present will of the country, in other words the exogenous or structural vulnerability. Resilience, as far as it depends on present and future policy, should not be a factor of a lower allocation. It is rather a factor of higher effectiveness and then a reason for allocating more resources to more resilient countries, in any case not less, while, as we argue, the more structurally vulnerable countries should receive more resources, ceteris paribus. Thus the distinction between structural vulnerability to climate change and resilience to climate change is needed both for logical and operational reasons. This paper is about the measurement of the structural vulnerability through an appropriate index.

In the recent political debate about the implications of climate change, the need of an index of vulnerability to climate change has been recognized, noticeably in United Nations circus. However, this recommendation has not made clear the kind of index required. As noted above the index should only reflect the structural factors of vulnerability to climate change. Moreover, the index should rely on a few components relevant, reliable, available for the whole set of developing countries and easily understandable, so that the index can be used in a transparent manner. In the search of such an indicator it seems useful to refer to two streams of

1 Ferdi
2 Cerdi-CNRS, Université d’Auvergne,
65 boulevard, F. Mitterrand
63000 Clermont-Ferrand, FRANCE
literature. First, the environmental literature offers various definitions and concepts of vulnerability, on which we draw, as far as needed, although we do not include in vulnerability the adaptive capacity and resilience, as done in this stream of research. Second, the endeavour to measure a structural economic vulnerability to external and natural shocks as led to building a related indicator named Economic Vulnerability Index (EVI) used in particular at the United Nations for the identification of the Least Developed Countries (LDCs) (United Nations CDP web site, Guillaumont 2009a 2009b). This index, which refers to the structural vulnerability, indeed includes components related to natural shocks (through “average of homeless due to natural disaster index” and “instability of agricultural production index”). But it is not focused on the long term vulnerability to climate change, and it only captures through the past recurrent shocks the likelihood they re-occur in a near future.

The present paper is (will be) organised as follows. In the first part, we present the various concepts of vulnerability and what we defined as structural vulnerability to climate change. In the second part, we discuss the composition of the index and its building.

1. What is vulnerability about?

In this section we review the main definitions of vulnerability to climate change and try to design a structural vulnerability to climate change. The “vulnerability of systems to climate change” is a burgeoning literature. It results from various fields of research such as climate science, disaster management and development economics. As recommended by Wam (2009), a greater synergy between ecologists and economics will be welcome. As also recognized for a long time, is the need to enhance the relationship between theoretical works and actual vulnerability assessments, so that this assessments can be formalized (Suppes, 1968).

1.1. The notion of vulnerability as it is used in development economics.


In development economics, the notion of vulnerability has been used mainly at the micro level; see in particular Christiansen et al. (2006), Barett (2003), Dercon (2005). More recently, it has been used at macro levels and with the search of measurable and comparable indices (this literature is reviewed in Guillaumont, 2009).
In this macro economic context, vulnerability is “the risk of being harmed by exogenous, generally unforeseen events or shocks” (Guillaumont, 2009). Relying on several decades of literature (in particular on export instability) this macro vulnerability is considered as an impediment to growth. The notion of economic vulnerability is formed by three main components: **shock, exposure and resilience.** Shocks are exogenous and generally unforeseen events (as instability of exports or as natural disasters such as typhoon, hurricane …). The exposure corresponds to factors that emphasize impacts of shocks. The resilience is the capacity to react to shocks.

The assessments of vulnerability retain all the three components or only one or two of them. When the three elements are considered, we attain a general assessment of vulnerability. When are only included the size of the shocks and the extent of exposure, the vulnerability considered is essentially a structural vulnerability. It is so because resilience is mainly related to policy factors. This is the kind of economic vulnerability that is captured by the economic vulnerability index (EVI) used by United Nations to identify the least developing countries (LDCs) (UN CDP report, 2005; Guillaumont, 2009).

1.2. **Vulnerability to climate change, can it be analyzed as economic vulnerability?**

The measure of vulnerability to climate change should reflect the vulnerability to environmental shocks resulting from climate change. These shocks may occur as various physical manifestations of climate change: droughts, floods, storms, long-term changes in the mean values of climatic variables such as temperature or rainfall and related changes in the instability of these former variables.

The vulnerability to climate change literature is recent but profuse: Adger (1999), Brooks (2003), Downing et al. (2001), Downing and Patwardhan (2003), Füssel (2005), Kelly and Adger (2000), O’Brien et al. (2004a), Olmos (2001). Two important points must be underlined about the framework of vulnerability to climate change: this concept must be distinguished from climate hazards assessments. Moreover, in the conceptual framework of “eco-sociological system, the distinction between social and biophysical vulnerability must be discussed.

Firstly, the climate change vulnerability must be distinguished from the assessment of impact of climate hazards, even if climate hazards are a part of climate change. The field of climate change is quite different from natural hazards field. In the former, researchers tend to focus on the concept of risk. In the social sciences and climate change, scientists prefer to talk in terms of vulnerability (Allen, 2003).

Secondly, Brooks (2003) distinguishes two kinds of vulnerability to climate change in the literature. First, vulnerability defined, by the environmental scientists, in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard (Jones and Boer, 2003; Nicholls et al., 1999). This field of research is based on natural hazard and focus on the concept of risk. In this context climate scientists view vulnerability in terms of the likelihood of occurrence and impacts of weather and climate related events (Nicholls et al., 1999). Brooks (2003) associates this definition to the biophysical vulnerability and to the natural hazards concept of risk. The second type of vulnerability is defined as “state that exists within a system before it encounters a hazard event” (Allen, 2003). This is, according to Brooks,
the definition of the social vulnerability. Social vulnerability is here represented as the set of socio-economic factors that determine people’s ability to cope with stress or change (Allen, 2003). Finally, the distinction made by Brooks (2003) led him to aggregate in a unique system the social and biophysical vulnerability.

The Brooks’ approach permits a better understanding of the vulnerability to climate change definition proposed by the IPCC (Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007): “Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity”. This definition is close to the definition presented in the first section. In this section, the literature on environmental vulnerability to climate change was reviewed, keeping in mind the distinction we have established about macro-economic vulnerability between shock, exposure and resilience. This will help us to put aside those components of vulnerability to climate change that are not structural, in others words that depends to a large extent on the present policy of countries and make them more or less resilient to shocks.

1.3. **Vulnerability to climate change and the distinction between mitigation and adaptation.**

The analysis of vulnerability to climate change undoubtedly meets the usual distinction between adaptation to and mitigation of climate change. To sum up the literature about mitigation and adaptation, there exist two alternatives in response to climate change: mitigation and adaptation. Adaptation primarily seeks to moderate the adverse effects of climate change through actions targeted on the vulnerable system by reducing system sensitivity or by reducing the consequent level of damage. The mitigation consists in limiting the number and the magnitude of potential climate hazards due to climate change through reducing the emissions of greenhouse gases, for instance. The mitigation has direct effects on the size of shocks while adaptation may either consist in lowering the exposure to shocks or enhancing the resilience. In order to have an index that can be used for the allocation of resources devoted to adaptation, it seems useful to focus on the structural need for adaptation, namely the structural components of the exposure to climate shocks. This could be illustrated by examining various works on climate change literature.

2. **Proposal for possible components of an Index of Structural vulnerability to Climate Change.**

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3 The economic analysis (inter-countries studies) exploits all the three dimensions of vulnerability, as the IPCC’s vulnerability definition. This example strengthens the fact that economic experiences must be a support to assess vulnerability to climate change.
An examination of the boiling literature on the economic consequences of the climate change lead to make a distinction between two kinds of risk resulting from this change: the risks of permanent shocks and the risks of recurrent shocks. Starting from this distinction, we identify some feasible indicators that can be used as relevant components of an index. Some of these indicators directly refer to the consequences of climate change, some are only proxies. Anyway, the set of the indicators presented below, should be considered more as an illustration of the principal elements rather than an exhaustive set of components. Anyway it should be remembered that a good index should be parsimonious, transparent, and focused on the most relevant issues, and, in our case, focused on the main economic issues raised by climate change.

2.1. Risks of permanent shocks

Risks of permanent shocks refer to possible events leading to persistent changes in the country. The two main kinds of risks seem to be the rise of the sea level and over-aridity and desertification.

2.1.1. The rise of the sea level

The assessment of the vulnerability to the sea level rise, illustrates well the need to distinguish between the size of shocks and the exposure. The assessment of the flood zones vulnerability reflects the exposure to the shock and the size of the shock. The exposure to sea-level rise depends on the relief, since it influences the liability to flooding. So the indicator chosen could be the distribution of the heights of arable lands. The shocks could be approximated by the distribution of the likelihood of sea-level rise in t years. The combination of the exposure and potential shocks allows assessing the liability to flooding resulting from the sea level rise.

\[ FL_i = \sum h_{ij} \cdot s_{ij} \]

With i, country indicator and j, the meters of sea level rising; \( h_{ij} \), probability that the sea level rises by j meters; and \( s_{ij} \), the part of arable lands below j meters.

2.1.2. Over-aridity and desertification

The literature on the consequences of climate change underlines the risk of some arid countries (in particular Sahelian countries) to be affected by the rise of temperatures and therefore to be threatened by over-aridity and desertification. Is it conceivable to find a proxy indicator of this risk? First, the exposure of such risk can be considered to depend on the average level of rainfall in the country. As a first approximation let us consider that the lower this level, the higher the risk to be affected. As for the size of the shocks is it possible to refer to the trend in the average level of temperature in each country over the past two or three decades. The hypothesis is that the rise of the world temperatures will be distributed over countries by the same way it has been during the last decades. More specific information on this specific future distribution could be used to make the assessment of the risk at the country level.
more relevant. An alternative proxy of this shocks measurement could be a decreasing trend in the average level of rainfall.
2.2. **Risks of recurrent shocks**

Many analysts of climate change argue that this change can generate more frequent or more acute natural shocks such as droughts, typhoons, floods, … In that field, it is possible to distinguish two kinds of recurrent shocks, some designed as level risks and some others designed as trend risks.

2.2.1. **“Level risks”**

The kind of risk, we called level risks, is already included among the components of the Economic Vulnerability Index (EVI). These risks are assessed “ex-post”. They are evaluated by a measure of an average level of instability. The two corresponding indicators of the EVI are the instability of agricultural production and part of homeless (percentage of population) due to natural disasters (other Center of Research on Epidemiological Disease indices could also be used such as population affected by natural disasters).

2.2.2. **“Trend risks”**

Here, the assessment of the risks of recurrent shocks is more forward looking. These risks are assessed “ex ante”. The issue considered is to know whether the recurrent shocks are likely to increase in the future. The proxies used in this aim can be the measurement of an upward trend in the level of instability. They are evaluated by the measurement of a trend of increasing instability. For instance, the proxy for risk on harvests can be the trend of increasing agricultural production instability, calculated as

\[
\left| Y_t - \bar{Y}_{at}\right| / \bar{Y}_{at} = f(t) = a \cdot t
\]

With \( a \) the trend in the level of instability, \( Y \) the production in year \( t \) and \( \bar{Y}_{at} \) the level of production in \( t \) considering the trend.

By the same way, the trend of the risk of natural disasters could be proxied by:

\[
H_{it} = f(t) = \mu \cdot t + c
\]

Where \( \mu \) represents the risk of increased natural disasters, under the conditions that the homelessness due to recent Tahitian earthquakes or Asian tsunami, since they are not related to climate change, is not included in the regression. To include them would be relevant only if the index calculated is an index of vulnerability to environmental shocks.

2.2.3. **Aggregating components**

Several methods of aggregating these components could be considered. The simplest one, although arbitrary, is to use the same weight between permanent and recurrent shocks and for each category of the main indicators we have designed (it would result in an index with four components: liability to flooding and risk of over-aridity for the permanent shocks, risks-level and risks-trend for recurrent shocks). More sophisticated methods for aggregating components will also be examined. After calculating the proposed indices to test the reliability and relevance, some conclusions will be drawn about the possibility to build on
a broad scale a tentative index of structural vulnerability to climate that more and more clearly appears sternly lacking.