Chapter 2
The Theory of the Micro-behavioral Economics of Global Warming

Abstract This chapter lays down the conceptual foundation for the micro-behavioral economics of global warming and describes its empirical model, the G-MAP (Geographically-scaled Microeconometric model of Adapting Portfolios in response to climate changes and risk) model.

Keywords Micro-behavioral economics · G-MAP · Selection · Climate risk

Micro-behavioral economics of global warming can be defined as the field of research on how individuals, individually or collectively, make decisions to cope with or adapt to changes in the climate system. It is founded on the long line of research efforts on how an individual makes economic decisions given specific circumstances and how these decisions affect markets (Samuelson 1938; von Neumann and Morgenstern 1947; Khaneman and Tversky 1979; Shiller 2003). It is the study of changes in individuals' behaviors in response to shifts in the climatic system (Seo 2006, 2010a).

Adaptation to global warming refers to changes in economic decisions by an individual or by a community of individuals in an effort to cope with changes in the climate regime (Mendelsohn 2000; Seo and Mendelsohn 2008a). An individual will adapt to climatic changes because it is economically sensible. That is, she/he will be able to avoid an otherwise large loss from global warming by adapting to it (Seo 2010a). Adaptation takes place efficiently at an individual level, barring negative or positive externalities. A public adaptation is the least cost approach if adaptation in question calls for a coordinated effort of a large number of parties (Seo 2011a). Adaptation will take place to cope with changes in climate means as well as changes in climate risk factors (Seo 2012b).

The micro-behavioral economics of global warming has taken shapes gradually in the process of quantifying the impacts of global warming on agriculture and natural resource enterprises. This is no surprise given that climate factors affect most visibly the farming and natural resource activities on the fields which are directly exposed to outdoor conditions. By contrasts, New York City is nearly fully

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air-conditioned in the summer and nearly fully heated in the winter while New Yorkers spend less than half an hour a day outdoors. That is, in agricultural and natural resource sectors changes in individuals' decisions in responding to climatic shifts are most prominent.

Even before global warming debates began at the international stage, researchers had examined how existing climate conditions have strong influences on agricultural productions especially in low-latitude developing countries (Ford and Katondo 1977; FAO 1978; Dudal 1980). In sub-Saharan Africa, agro-climatic conditions are adverse in most parts of the continent with two-thirds of the rural population residing in arid, semi-arid, and desert zones (World Development Report 2008). Annual rainfall is extremely low in many areas and only 4 % of the croplands in the continent are irrigated (Reilly et al. 1996; FAO 2012). Temperature, rainfall, and soil conditions influence agricultural activities by determining the length of crop growing periods of farming areas (Dudal 1980; FAO 2005). Climatic factors affect the outbreaks of crops and livestock diseases and their frequencies (Ford and Katondo 1977; Ziska 2003). A multi-decadal shift in rainfall in West Africa makes it difficult for farmers to grow crops successfully for a long period of time (Hulme et al. 2001; Shanahan et al. 2009).

In South America, farmers have adjusted their practices to the available pasturelands which are more than four times larger than the croplands in Brazil and even eight times larger in Argentina, which in turn depend upon climate regimes (Baethgen 1997). South American farmers earn about 35 % of their income from forest related activities as the continent has the largest forest cover in the world (defined as >50 % cover) which accounts for 44 % of the total land area in South America (WRI 2005; Vedeld et al. 2007). A highly volatile intra-annual variation in rainfall along the high Andes Mountain ranges has been considered as one of the big obstacles to farmers in Latin America who should adapt (Magrin et al. 2007).

Given these backgrounds, there is neither mystery nor surprise in that from the initial report by the Intergovernmental Panel on Climate Change, agriculture has been at the center of the debates on potential impacts of global warming, along with sea level rises. The initial report shows that the response function of plant growth rate (and net photosynthesis) to the range of temperature is a hill-shaped function with a peak (optimal) temperature beyond which it falls sharply, based on the existing plant science literature (IPCC 1990). Reflecting the steeply sloped quadratic yield response function, the first generation assessment models reported that one third of the total global warming damage in the US, including both market and non-market sector damages, will occur solely from the agricultural sector (Cline 1992; Pearce et al. 1996). The impacts on developing countries were reported to be twice as large as those expected in temperate climate region countries (IPCC 1990; Reilly et al. 1996, Rosenzweig and Hillel 1998). Further, early studies projected that people at the risk of hunger will increase by as much as 50 % (by 300 million people) under the United Kingdom Meteorology Office (UKMO) scenario by the year 2060 due to large price increases of staple crops (Rosenzweig and Parry 1994).

The early assessment models by and large had no capacities to model adaptation decisions, let alone capture them in their assessments (Mendelsohn et al. 1994). If today's agricultural decisions and productivities are so heavily dependent upon the current climate factors as these early studies were demonstrating, it is only natural to think that future decisions will also be changed if the climate factors are altered (Seo 2006; Seo and Mendelsohn 2008a). This is because agricultural and natural resource profits to a large degree arise from productivities and distributions of ecosystems which will be altered by climatic shifts (Seo et al. 2009; Seo 2014).

What changes do we expect in natural resources, ecosystems, or ecologies if the global climate system shall be shifted in the future? Experimental studies have made strides in answering this question over many decades. Climate changes would affect agriculture directly as well as indirectly (Reilly et al. 1996; Gitay et al. 2001). Increased CO_2 in the atmosphere alters the productivities of various ecosystems by affecting the photosynthetic processes (Schlesinger 1997). Elevation in carbon concentration increases crop growth in the approximate range from 17 to 35 % and net photosynthesis (Ainsworth and Long 2005; Tubiello et al. 2007). The yield increases are in general larger in C3 crops than in C4 crops.[1] Changes in climatic conditions such as temperature and precipitation patterns influence crop and plant growth, e.g., by altering growing seasons (Reilly et al. 1996; FAO 2005). An increase in climate variability also affects crop growth, which may cross a threshold for a certain crop variety (Easterling et al. 2000; Porter and Semenov 2005; Challinor et al. 2007). Temperature and precipitation changes modify the direct CO_2 elevation effects on crops (Easterling et al. 2007). The degree of vulnerability varies across the major crops such as wheat, maize, rice, soybeans, cotton, millet, cassava, sorghum, rubber, groundnuts, citrus, and cocoa among many species and varieties (Gitay et al. 2001; Ainsworth and Long 2005). Within a crop species, a more heat tolerant genotype, e.g., Indica rice, is sometimes discussed (Matsui et al. 1997). The degree of vulnerability depends on the associated limiting factors such as nutrient and water availability and plant-soil interactions in the field (Lobell and Field 2008). Changes in climate and CO_2 level also lead to the changes in growth and distributions of weeds, insects, and plant diseases that affect the conditions of agricultural lands (Patterson and Flint 1980; Porter et al. 1991; Sutherst 1991; Ziska 2003).

Over the past decade, animal systems have gained increasing attention. Animal husbandry accounts for 52 % of the agricultural value of sales in the US and 49 % of the farms in the country own livestock while the livestock sector is growing rapidly in developing countries (Delgado et al. 1999; USDA 2007; Thornton and Gerber 2010). In Africa and Latin America, more than two thirds of the farms own some livestock species (Seo and Mendelsohn 2008a, b). Farmers in sub-Saharan Africa own animals along with crops, but as much as 20 % of the South American farms specialize in animals (Seo 2010a, b). Major animals raised around the world

[1] Most crops are C3 crops. Notable C4 crops are maize (corn), millet, sugar cane, and sorghum.

are beef cattle, dairy cattle, goats, sheep, chickens, pigs, donkeys, beehives, and horses while major animal products are beef, milk, butter, cheese, wool, and eggs, but animal portfolios differ across the continents (Nin et al. 2007; Seo and Mendelsohn 2008a; FAO 2009; Seo et al. 2010).

Changes in CO_2 concentration, temperature, and precipitation patterns all influence the productivities of animals both directly and indirectly (Johnson 1965; Baker et al. 1993; Hahn 1999; Parsons et al. 2001; Mader 2003; Mader et al. 2009). Climatic changes affect heat exchanges between animals and the environment, which then affect weight growth, milk production, wool production, egg production, and even conception rates (Amundson et al. 2006; Mader et al. 2009; Hahn et al. 2009). Heat tolerance of animals, however, may vary across animal species, i.e., some animals are more or less tolerant (Seo and Mendelsohn 2008a). A more heat tolerant breed of a species is often discussed, e.g., Brahman cattle (Bos Indicus) which are widely raised in Asia, the US, South America, and Australia or a mixed-breed (Hoffman 2010; Zhang et al. 2013). Changes in productivities of ecosystems due to global warming imply that animal husbandry can expand when grasslands increase by decreasing either forests or croplands (Viglizzo et al. 1997; Sankaran et al. 2005; Fischlin et al. 2007). Forage quantity, quality, and grazing behaviors can be altered by elevated CO_2 (Campbell et al. 2000; Shaw et al. 2002; Polley et al. 2003; Milchunas et al. 2005). Changes in precipitation patterns associated with a warming world may also alter the frequency and severity of livestock diseases such as Nagana (Trypanosomiasis) carried by Tsetse flies in Africa, cattle tick in Australia, and blue tongue that affects sheep and goats in Europe (Ford and Katondo 1977; White et al. 2003; USAHA 2008; Fox et al. 2012). An intensive livestock production system, in contrast to a pastoralist system, has more control on the exposure of animals to climate factors by utilizing barns and shelters, air conditioning, shading, and watering (Hahn 1981; Mader and Davis 2004). The former is, however, more dependent on alternative feed (e.g. grains from crop productions) availability than the latter (Adams et al. 1999).

The changes in biogeochemical processes and animal systems described so far in this chapter will inevitably lead to changes in behavioral decisions of those who are working in agricultural and natural resource enterprises. A micro-behavioral model of adaptation strategies starts with an individual farm, which is in a stark contrast to either the experimental models or the agro-economic models which starts with a single crop (Seo 2006; Seo and Mendelsohn 2008a). To put it differently, the micro-behavioral models are concerned with an individual's decisions whereas the other models are concerned with the changes in crops' natural characteristics.

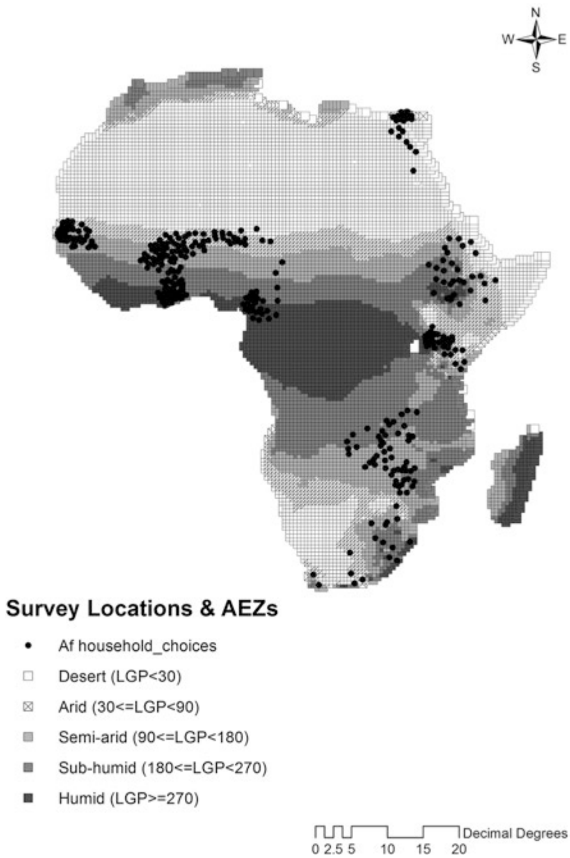
Sampling is conducted across the entire region of concern, e.g., South America or sub-Saharan Africa, so that the model can encompass the full variety of farm portfolios of natural resources managed in the regional economy of concern (Seo 2012a, 2014). This also ensures that the full variety of agricultural and natural resource enterprises is captured by the model.

While the agro-economic models and the econometric studies of yields which are necessarily constrained to major grains such as wheat, maize, rice, cotton, and soybeans (Adams et al. 1990; Schlenker and Roberts 2009), the micro-behavioral models include all the major and minor grains, vegetables, oil seeds, fruits, tree products, and numerous animals and animal products that are managed across the entire region of the concern (Seo 2012a, 2014). In addition, a full variety of farms including commercial farming, family farming, subsistence farming, specialized farming, and integrated (diversified) farming are all included for modeling (World Bank 2009; Seo and Mendelsohn 2008a; Seo 2010a).

Viewed from the angle of ecosystem diversity, while the agro-economic models—these models are the primary subject of Chap. 4 of this book—are based on the experiments conducted on selected sites, or laboratories, located in a certain ecosystem, a micro-behavioral modeler randomly samples rural households from a large geographical space such as the entire African continent. Therefore, one can capture the full complexity of ecosystems or ecological zones that are present in the continent of research concern (Seo 2012a, b).

In Fig. 2.1, the present author maps the locations of household surveys collected across the African continent by the World Bank Project on climate change and

Fig. 2.1 African household surveys across agro-ecological zones



African agriculture (Dinar et al. 2008; Seo et al. 2009). Household locations are overlaid on top of the five Agro-Ecological Zones (AEZs) defined by the Food and Agriculture Organization (FAO) of the United Nations: deserts, arid, semi-arid, sub-humid, and humid zones (Dudal 1980; FAO/IIASA 2005).[2] Household surveys, as depicted by the black dots in the map, were collected from all the five AEZs which are located in eleven different countries across the five different sub-regions of Africa: Niger, Burkina Faso, Senegal, Ghana from West Africa; Kenya, Ethiopia from East Africa; Cameroon from Central Africa; Egypt from North Africa; Zimbabwe, Zambia, South Africa from Southern Africa. Survey locations also include high mountains such as the Kilimanjaro, lowlands in West Africa, grand rivers such as the Congo River, lake zones in East Africa, landlocked countries, and deserts such as the Sahara, the Namib, and the Kalahari (Seo 2012b).

In the micro-behavioral economics of global warming, given the external factors such as climatic and geographic conditions, a natural resource manager is assumed to maximize the long-term profit from managing agricultural and natural resources. Conditional on the external factors, she/he chooses a natural resource portfolio from the full variety of portfolios available and makes decisions on the inputs and outputs of productions in order to maximize the profit from the portfolio of choice (Seo 2006, 2010a).

If climate shall be altered from the current state to the future states owing to continued accumulation of greenhouse gases in the atmosphere resulting from ever-growing anthropogenic economic activities, the natural resource manager would adapt by adopting an agricultural portfolio as well as by altering the inputs and outputs of productions, resulting in the changes in the long-term profits earned from agricultural and natural resource enterprises.

Therefore, in the framework of micro-behavioral economics, researchers can reveal, among other things, or make explicit the following decision variables of great concern to global warming debates. First, they can show how the choices of natural resource portfolios are made currently and will be altered due to climatic shifts. Second, they can show how each of the agricultural and natural resource portfolios will suffer (or gain) from global warming in terms of the long-term profits earned over time. Third, they can show how the natural resource enterprises as a whole will fare under a variety of scenarios of global warming (Seo 2010b, 2013).

The empirical model of the micro-behavioral economics was named the G-MAP model short for the Geographically-scaled Microeconometric model of Adapting Portfolios in response to global warming) (Seo 2010a, 2011b). The rationale for the name is that the G-MAP model examines Micro behavioral adaptation decisions with econometric models, includes a full array of farm Portfolios in the analysis, quantifies explicitly Adaptation choices in the context of resultant profits, and is calibrated to integrate adaptation decisions with Geography and ecosystems. The G-MAP can further connote a guide map for adaptations to

[2] A full description of the AEZ classification will come in Chap. 6. A more refined definition of the ecosystems of Africa is certainly possible and a number of alternative versions are already available (Seo 2013, 2014).

global warming, which was the initial motivation of the author in developing the model and its applications.

Henceforth, the present author provides a full description of the G-MAP model (Seo 2010a). A natural resource manager (n) is assumed to choose one of the agricultural and natural resource enterprises (j) to maximize the expected long-term profit (π), given exogenous factors. That is, her/his problem is written as follows:

$$ArgMax_j\{\pi_{n1}, \pi_{n2}, \ldots, \pi_{nJ}\}. \tag{2.1}$$

What are agricultural and natural resource enterprises? South America, more than anywhere else, provides an excellent case study for the diversity of rural activities and natural resource enterprises. In South America, a great large variety of crops, animals, and forest products is managed by the rural residents. A third of the total land area in South America is agricultural lands (World Resources 2005). Major crops planted are cereals such as wheat, maize, rice; oil seeds such as soybeans, peanuts, sunflowers; vegetables such as potatoes and cassavas; and various specialty crops such as cotton, tobacco, and coffee.

In addition to crop farming, animal husbandry holds much significance to South America rural areas. The continent is vastly occupied by the grasslands which differ in types and qualities. Pasturelands used for livestock are four to eight times larger than the croplands in major countries such as Argentina and Brazil (Baethgen 1997). Argentina and Brazil are the world's largest beef cattle exporters as well as the largest consumer of beef per head annually (Steiger 2006). Along with different varieties of beef cattle, most frequently raised animals are dairy cattle, chickens, pigs, goats, and sheep (Seo et al. 2010).

Besides crops and animals, forests and forest products are a vital component of the rural economy in South America. Much of the continent is covered by different types of forests (Matthews 1983). The Amazonia covers 7.5 million km^2 and is the world's largest pluvial forest (Mata and Campos 2001). Forest income may account for more than 20 % of the rural income in South America (Peters et al. 1989; Vedeld et al. 2007). People manage tree plantations for the sale of timber products, non-timber forest products, household uses, or even for carbon credits. Most common trees reported by the rural households are as numerous as mango, pineapple, cashew, citrus, cacao, banana, palm, shea nut, apple, Kola, peach, almond, prune, apricot, avocado, cherry, hickory, eucalyptus, lemon, and Brazil nut (Seo 2012a).

From the whole array of agricultural and natural resource portfolios rural households manage, we can classify the enterprises based on whether an individual household manages crops or not, whether it manages livestock or not, and whether it manages forests or not. The combinations of crops, livestock, and forests lead to the following enterprises:

Enterprise 1: Crops-only
Enterprise 2: Livestock-only
Enterprise 3: Forests-only
Enterprise 4: Crops-livestock
Enterprise 5: Crops-forests

Enterprise 6: Livestock-forests
Enterprise 7: Crops-livestock-forests

The first three enterprises are specialized in that they specialize either in crops or livestock or forestry. The latter four are diversified enterprises in that they mix at least two of the three categories. Empirically, examinations of household responses reveal that enterprise 6, a mix of livestock and forests, is very rarely found (Seo 2012a).

Let the profit of the farm (n) from agricultural and natural resource enterprises 1 and j be written as the sum of the observable component and the unobservable component while the observable component can be written as a linear function of the parameters as follows (Dubin and McFadden 1984):

$$\pi_{n1} = X_n\beta_1 + u_{n1} \tag{2.2a}$$

$$\pi_{nj}^* = Z_n\gamma_j + \eta_{nj}, \quad \mathrm{j} = 1, 2, \ldots, \mathrm{J}. \tag{2.2b}$$

The π denotes the observed profit while the π^* denotes the latent profit, i.e., the profit expected when the enterprise is chosen by the farm (n). The subscript j is a categorical variable indicating the choice amongst J enterprises.

Let's say for the purpose of the discussions to follow that $j = 1$ denotes a specialized crop system, $j = 2$ an integrated crops-livestock system, and $j = 3$ a specialized livestock system. Let's assume for the moment that the three choices are mutually exclusive and exhaustive. The vector Z represents the set of explanatory variables pertinent to all the alternatives and the vector X contains the determinants of the profit of the first alternative, the crops-only enterprise.

The vectors Z and X include as components climate variables. Climate variables encompass both climate normals and climate risk normals (Seo 2012b). Seasonal climate variables are used to capture changes in climate conditions in spring, summer, fall, and winter (Mendelsohn et al. 1994). In the Southern Hemisphere, seasons are defined using opposite seasons in the Northern Hemisphere. That is, summer season months (June, July, August) in the Northern Hemisphere correspond to winter season months. A more precise seasonal definition can be made for the region of research interests. Climate variables enter into the model in a nonlinear specification to capture nonlinear effects of climate.

The error term in the profit equation in Eq. 2.2a is assumed to be independently and identically distributed (iid) with the following mean and variance given the explanatory variables:

$$E(u_{n1}|X, Z) = 0, \quad Var(u_{n1}|X, Z) = \sigma^2. \tag{2.3}$$

The probability to choose each of the natural resource enterprises is calculated based on the profit equations, Eq. 2.2b, and the rule in Eq. 2.1. The estimation of the choice equation calls for the description of the unobservable term in Eq. 2.2b. Depending upon the assumptions, the parameters are estimated parametrically or non-parametrically (Train 2003).

Assuming $\eta_{nj}'s$ are iid Gumbel distributed (McFadden 1974; McFadden and Train 2000) and spatial neighborhood effects are controlled by re-sampling at the level of the neighborhoods in a large number of times (Anselin 1988; Case 1992; Seo 2011b), the choice probability of the farm n choosing natural resource enterprise 1 can be written as the sample average of the following Logit probabilities of the samples:

$$P_{n1} = \frac{\exp(Z_n \gamma_1)}{\sum_{k=1}^{K} \exp(Z_n \gamma_k)} \tag{2.4}$$

Having chosen enterprise 1, the farmer makes numerous decisions regarding inputs, outputs, and a variety of practices to maximize the expected profit from managing the chosen system. These decisions are variable in the short-term. They can be daily, weekly, monthly, quarterly, or yearly measures used to manage each of these chosen enterprises to cope with specific weather conditions occurring or expected with confidence in the near term.

The conditional profit of the selected enterprise can be estimated directly using Eq. 2.2a and X with the same assumption of the error terms. However, because enterprise profits are observed only for the farms that actually chose natural resource enterprise 1, the direct estimation of Eq. 2.2a will be biased because of the selection decision (Heckman 1979). Selection biases must be then corrected to obtain consistent estimates of the parameters in the profit equations.

For a multinomial choice model or in a polychotomous decision situation, there are a number of selection bias correction methods that have been proposed since Heckman. The Lee's generalized method, the Dahl's semi-parametric method, and the Dubin-Mcadden's method are most widely discussed and used (Lee 1983; Dubin and McFadden 1984; Dahl 2002). The Dubin-McFadden's method outperforms the other methods because the other methods place severe restrictions on the correlation structure among alternatives (Schmertmann 1994; Bourguignon et al. 2004). The only exception is when the choice sample is too limited, in which case the Lee's method can perform as well.

Following Dubin and McFadden (1984) for the selection bias correction for a multinomial choice situation, we assume a linearity condition, i.e., the correlation coefficients (λ_j) between enterprise 1 and enterprise j add up to one across j, allowing for a markedly more flexible correlation matrix than the other methods:

$$\sum_{j=1}^{J} \lambda_j = 1 \quad \text{where } \lambda_j = \text{corr}(u_1, \eta_j) \tag{2.5}$$

The conditional land value (or profit) function for the first enterprise is then consistently estimated as follows:

$$\pi_{n1} = X_n \varphi_1 + \sigma \cdot \sum_{k \neq 1}^{J} \lambda_k \cdot \left[\frac{P_{nk} \cdot \ln P_{nk}}{1 - P_{nk}} + \ln P_{n1} \right] + \delta_{n1} \tag{2.6}$$

In the above equation, δ is a white noise error term with zero mean. That is, the parameter estimates from the above equation are unbiased and consistent. The conditional land value function for the specialized livestock system or the mixed system is estimated in the same manner through Eqs. 2.4 and 2.6.

The choice equations are identified non-parametrically. The exact identification strategy is to exclude from the outcome (land value) equations the variables that affect the choices of natural resource enterprises but not the land value functions (Fisher 1966; Johnston and DiNardo 1997).

Among the explanatory variables (X) in the G-MAP models are climate variables, primary variables of interest to climate researchers. Climatic variables can be either satellite data or ground weather station data. The satellite data are available from the late 1980s from the various instruments aboard the National Aeronautic and Space Administration (NASA) satellite programs (Basist et al. 1998; Mendelsohn et al. 2007, Seo et al. 2009). The weather station observation data are available collected historically by the national government organizations, e.g., from more than 16,000 weather stations around the world (New et al. 2002).

Besides climate variables, other control variables are soils, topology, hydrology (water flows and runoff), market access (travel hours to major markets for exports, sales, or inputs), household characteristics (gender (female), education (schooling), number of family members, etc.), policy variables (extension service), and country dummies (Seo 2011b, 2013). These data are obtained from the various geographically referenced data sources, which we will have opportunities to discuss further in the Chapters to follow.

From the estimated probabilities in Eq. 2.4 and the conditional land values (profits) for different enterprises in Eq. 2.6, the expected land value (profit) of the farm (n) is calculated as the sum across the enterprises of the probability of each natural resource enterprise to be adopted times the conditional land value of that enterprise given the external conditions. Let E be the climate factors. Then the expected land value is derived as follows, all other factors remaining unchanged:

$$W_n(E) = \sum_{j=1}^{J} P_{nj}(E) * \pi_{nj}(E) \tag{2.7}$$

Let's pick a climate scenario in which E changes from E_0 to E_1. Then, the change in welfare, ΔW, resulting from the climate change scenario can be measured as the difference in W after and before climate change as follows:

$$\begin{aligned} \Delta W_n &= W_n(E_1) - W_n(E_0) \\ &= \sum_{j=1}^{J} P_{nj}(E_1) * \pi_{nj}(E_1) - \sum_{j=1}^{J} P_{nj}(E_0) * \pi_{nj}(E_0) \end{aligned} \tag{2.8}$$

Note that the change in the expected land value (farm profit) in Eq. 2.8 captures both the changes in the probabilities that a farm will be a particular enterprise and the changes in the conditional profits that would be generated by the enterprises.

Uncertainties surrounding the estimates of the G-MAP models are provided by constructing 95 % confidence intervals. The changes in the choice probabilities (Eq. 2.4), the changes in the enterprise-specific conditional land values (Eq. 2.6), and the changes in the expected farm land value (Eq. 2.8) are calculated and bootstrapped by randomly sampling a large number of times from the original sample (Efron 1981).

The climate system, E, needs further elaborations, which is the primary variable of interests in all climate studies. The G-MAP model, like other climate economics models, is initially developed to measure the impacts of climate normals on individuals' behaviors and economic profits. That is, the purpose of the G-MAP models is not to quantify the impacts of weather in a specific year. The distinctions between weather and climate normals are essentially important in the climate science literature (Le Treut et al. 2007). Weather may be hotter this year, colder next year, and so on. However, these weather fluctuations may or may not have little to do with climate. Climate is defined to be the average of weather realizations for the long time period, e.g., 30 years. For this reason, it is called climate normals.

In the G-MAP models, temperature normals and precipitation normals are used for climate variables. Temperature normals are a 30-year average of temperature variables while precipitation normals are a 30-year average of precipitation variables. To capture different stages of crops and vegetation growth, the G-MAP models have relied on seasonal climate normals: spring, summer, fall, and winter. In the low-latitude countries where four seasons are not distinct, summer and winter seasons are used for climate normals (Seo and Mendelsohn 2008a, b).

In the G-MAP models, climate normals include both climate means and climate risk normals in the form of temperature and precipitation variabilities. Climate risks are not the same as weather risks (fluctuations) on which past studies of African agriculture have concentrated (Udry 1995; Kazianga and Udry 2006). A village may suffer from occasional weather shocks such as a drought or a flood but it can still be a low climate risk zone if such occurrences are not frequent in the long-term.

A long-term variability of rainfall can be captured by the Coefficient of Variation in Precipitation (CVP) measured from many decades of observations, i.e., for the 30-year period from 1961 to 1990. The CVP is a measure of rainfall dispersion that does not depend on the unit of measurement and can be defined as follows with R_{kj} being monthly precipitation in month j and year k (K = 30) and $\bar{R}_j$ being 30-year average rainfall for month j:

$$\mathrm{CVP_j} = \sigma_j / \bar{R}_j \quad \text{where } \sigma_j = \sqrt{\sum_{\mathrm{k=1}}^{\mathrm{K}} (R_{kj} - \bar{R}_j)^2 \Big/ (K-1)} \tag{2.9}$$

Another major concern with regard to climate risks is that climate change will lead to more frequent occurrences of extremely hot days and cold days and/or more variable temperature (IPCC 2001; Tebaldi et al. 2007). This implies an increase in the range between maximum temperature and minimum temperature, altering growing periods for crops (Easterling et al. 2000; FAO 2005; Schlenker and Roberts 2009). The temperature range can be measured by the Diurnal Temperature Range (DTR). Average monthly DTRs for the 30-year period mentioned above have been measured by the CRU data set (New et al. 2002). Let $T_{\max}$ be daily maximum temperature, $T_{\min}$ daily minimum temperature, j day, m month, and K year. Then, the DTR for month m is defined as follows:

$$\mathrm{DTR_m} = \frac{\sum_{k=1}^{K}\sum_{j=1}^{J}\left(T_{k,m,j},\mathrm{max} - T_{k,m,j},\mathrm{min}\right)}{J * K}. \tag{2.10}$$

Researchers should notice that the dependent variable in the G-MAP models too captures fully the fluctuations of farm profits year by year. That is, it is the net present value, with discount rates applied, of the stream of yearly rents (profits) expected in the future on the land, i.e., the value of the land (Fisher 1906; Seo 2013). This expectation is formed by decades of past experiences of farming on the land given climate and geographical conditions. As such, the decision to adopt a natural resource enterprise is not motivated by annual weather conditions, but rather on the long-term climate of the region, i.e., climate normals. The expected return will also include household consumption of produced goods and family labor hours used for the enterprises if rural households should exchange such goods and services at the market places otherwise (Seo 2006; Seo and Mendelsohn 2008a).

The G-MAP modeling originated from the Ricardian model which was intended to capture farmers' substitution behaviors of inputs to the full extent when climate were to be altered (Mendelsohn et al. 1994). In the Ricardian model, adaptation behaviors remained implicit, for which reason the model is sometimes referred to as a black box. The G-MAP models make these adaptation behaviors explicit (Seo 2006). That is, changes in farm choices of enterprises or species are modeled explicitly (Seo and Mendelsohn 2008a; Seo 2010a).

The Ricardian method that estimates the net revenue or land value in a reduced form as a function of climatic variables have also been applied widely across the world from the US to India, Canada, Sri Lanka, Africa, Brazil, South America, China, and Mexico (Mendelsohn et al. 1994; Maddison 2000; Kumar and Parikh 2001; Reinsborough 2003; Seo et al. 2005; Schlenker et al. 2005; Kelly et al. 2005; Kurukulasuriya et al. 2006; Timmins 2006; Kurukulasuriya and Ajwad 2007; Seo and Mendelsohn 2008b; Sanghi and Mendelsohn 2008; Wang et al. 2009). The Ricardian method is also applied to a panel random-effects model (Masseti and Mendelsohn 2011).

The paper by Mendelsohn et al. (1994) published two decades ago sowed the seed of the economic studies on the impacts of climate change conducted ever since its influential publication, including the ones cited above, by laying the conceptual foundation that farmers are not dumb, therefore will fully adapt to changes. The micro-behavioral economics studies have emerged naturally from the Ricardian models and have endeavored to unpack what is inside the Ricardian black box, i.e., adaptation strategies and consequences. One of the major goals of this book is, therefore, to present the major results on adaptation strategies from the different versions of the G-MAP model applied to sub-Saharan and South American agricultural and natural resource enterprises. This will in turn help clarify for the serious readers of the book the concepts and theories put forth in this Chapter.

Before closing this Chapter, it is pertinent at this point to mention the policy-directed nature of the micro-behavioral economics and the G-MAP models, although formal discussions will surely be followed in the ensuing Chapters.

The field and the modeling in its conception were originated from the fundamental question of "What adaptation strategies should be taken to adapt to climate changes?" The major findings from the applications of the models provide highly policy relevant research outcomes. In particular, while the world communities have recently established the Green Climate Fund (GCF), there has been no reasonable attempt to figure out how to distribute the funds into different projects of adaptation and mitigation into different countries (UNFCCC 2011). Lack of serious studies on this issue is a big hurdle for the countries which are considering pledging their contributions. Recent global warming negotiations were swamped by the disputes on the allocations and unfulfilled promises of fund contributions. The micro-behavioral economics provides a conceptual layout for answering this important policy question.

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