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Research paper

Climate change and crop choice in Zambia: A mathematical programming approach

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ABSTRACT

While climate change is widely regarded as a threat to food security in southern Africa, few studies attempt to link the impacts of climate change on agriculture with the specificities of smallholder livelihoods. This paper presents a set of farm household models in Zambia built in order to assess the impacts of climate change on rural households across different agro-ecological regions and household types. The models combine several techniques, including linear programming of farm-level decision making, regression analysis to estimate crop yields for the year 2050, and stochastic simulation to incorporate an uncertain climate. The models are parameterized with household survey data and calibrated to best reflect present-day crop distributions at each site. Results indicate that, under the diverging climate change scenarios of two contrasting general circulation models (HadCM3 and CCSM), farmers will likely shift their choices of technologies and crops. Among smallholder farms, calorie production from field crops is estimated to decrease by 1.17–5.44%. Although farm households are expected to meet their consumption requirements, the probability of falling below a minimum threshold of crop calorie production rises, particularly for smallholders who face binding land constraints. Given the current choice set, autonomous on-farm adaptation will not be enough to offset the negative yield effects of climate change. Thus, larger-scale interventions are needed to provide farmers with additional adaptation options.

1. Introduction

Climate change is widely regarded as a multiplier of existing threats to food security in southern Africa (Kotir, 2011).[1] In Zambia, where over 90% of smallholder crop production is rainfed, inter-annual variability in climatic conditions is an important determinant of crop output and food security (Siegel and Alwang, 2005). For this reason, climate change is likely to exacerbate conditions for rural households, posing a challenge to agricultural development. However, the literature on farm-level adaptations to climate change is thin (Auffhammer and Schlenker, 2014), with a lack of analyses that evaluate the impacts of climate change while directly considering the behavior of smallholder households (Morton, 2007).

As noted by Burke and Lobell (2010), climate change "will not confront a static world", but rather one in which farmers and policy makers will likely adapt to the associated challenges and opportunities. In this context, adaptation is defined as any adjustment made in social or economic systems in response to (or in expectation of) the effects of climate change. Smit et al. (1999) distinguishes between 'autonomous adaptations' which would likely occur in the absence of policy intervention, and 'planned adaptations' that modify the vulnerability of entire systems to climate change. Autonomous adaptations include the farm-level selection of a new crop mix from existing choices, or the adjustment of a household's income sources in response to climate stress. If simple, farm-level measures are able to offset any expected losses, then significant interventions may not be necessary to protect a population's welfare (Burke and Lobell, 2010). However, where autonomous adaptations are likely to come up short, a more 'active' sort of adaptation will be needed, including investment

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[1] Several abbreviations used in this paper are not standard in the field: AE (adult equivalent); ZMK (Zambian kwacha); and CFS (Crop Forecast Survey).

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in infrastructure, the development of new crop varieties suited to a changing climate, and policies to promote and facilitate adaptive behavior. Thus, it is imperative to understand the likelihood of autonomous adaptation in order to identify the most beneficial planned adaptations.

Despite the relevance of this topic, studies of the food security impacts of climate change often assume zero or complete adaptation. In the first case, the economic effects of climate change are determined only by the link between climate and agricultural yields, such that crop choice is treated as exogenous (a 'dumb farmer' approach). Yet farmers do select adaptation strategies from within their choice sets, including the adoption of new crops, cultivars, and management regimes (Kurukulasuriya and Mendelsohn, 2008; Moniruzzaman, 2015; Seo and Mendelsohn, 2008). *Ceteris paribus*, it can be expected that farmers will allocate more land and inputs to the crops that are least negatively affected by, or benefit from, climate change. To overlook such behavior is to overestimate the expected damage from climate change. In contrast, the 'Ricardian approach' assumes that farmers will select the crops and management practices most appropriate to a new climate (Seo and Mendelsohn, 2008), thereby assuming complete and effortless adaptation.[2] However, while acknowledging the potential for adaptation, it is important to note that such strategies are not always available: Food insecure households face a limited choice set due to the costs and perceived risks of adaptation, imperfect access to input and output markets, and lack of insurance and credit. Overstating the choice set of farmers results in overestimating the potential gains from adaptation.

It should also be noted that most studies of climate change impacts on agriculture have been carried out at a relatively low spatial resolution, such as the national, regional, or global scale (Thornton et al., 2010). Yet the household level is where food scarcity is ultimately experienced and where decisions about production, investment, and risk management are made in most rural societies. Thornton et al. (2010) observe that there remain "real difficulties in making the connections between relatively coarse climate models and the spatial and temporal scales at which appropriate adaptation information is really needed". The Intergovernmental Panel on Climate Change has therefore stressed the importance of assessing the effects of climate change and possible adaptation strategies at the agricultural system or household level (IPCC, 2014). However, as Morton (2007) observes, few studies connect the science of climate change impacts on agriculture with "the specificities of smallholder and subsistence systems".

This paper employs a mathematical programming (MP) farm household modelling approach to better understand the trade-offs that drive farmer decisions under a changing climate. This type of whole-firm optimization model integrates the multiple objectives, activity options, and constraints faced by a typical (or 'representative') farm household (Hazell and Norton, 1986). By including a realistic set of activities and constraints, the model is able to consider the opportunity costs of different activity mixes, acknowledging that new crops or cultivars are not adopted solely on the basis of productive potential (Hazell and Norton, 1986). Another strength of MP models is their ability to model circumstances that have yet to be empirically observed. However, in a recent literature review of farm or farm household models that incorporate climate conditions into the model, van Wijk et al. (2012) find that just 3% of the publications considered were of climate change adaptation or mitigation, and 3% represented smallholders or farm-households. In this paper, we begin to fill this gap in the literature by constructing a set of farm household models in Zambia, and then simulating household behavior with the expected yields predicted under climate change scenarios.

This paper makes several contributions: First, it moves beyond common assumptions regarding the likelihood of on-farm adaptation to climate change through the use of mathematical programming. This enables us to provide quantitative estimates of the ability of households to adapt their farming systems to improve food security outcomes, which few studies have done (Burke and Lobell, 2010). Second, this paper highlights the heterogeneity of rural households with a set of models that are specific to different agro-ecological regions and types of households in Zambia, including smallholder households and so-called 'emergent' farmers, with somewhat larger landholdings. This allows us to explore which households are most vulnerable and, conversely, which are able to autonomously adjust their cropping practices to alleviate the effects of climate change (Burke and Lobell, 2010; Thornton et al., 2010). Third, in addition to identifying a point estimate of climate change impacts on household production, we account for the probabilistic nature of agricultural production through a Monte Carlo simulation in which rainfall and temperature enter the model stochastically. A number of authors have similarly combined MP models with a stochastic simulation of climate variables (Hansen et al., 2009; Keil et al., 2009; Letson et al., 2005), though rarely with a focus on climate change adaptation (see van Wijk et al., 2012).

The remainder of the paper is organized as follows: Section 2 summarizes the data sources and introduces our study sites. Section 3 describes the construction of the farm household models and explains the statistical method used to estimate the yield impacts of climate change. Section 4 provides model results, including a validation of model solutions at baseline, the model predictions under two climate change scenarios, and a simulation of smallholder vulnerability to production shortfalls. Section 5 concludes with a summary of findings and discussion of policy implications.

2. Data sources and study sites

The construction of a farm household model requires, at minimum, information on crop budgets and yields and the cropping behavior of 'representative' households in a given location, as well as their land, labor, and cash constraints. To this end, we draw from several household-level data sets for rural Zambia. These include a series of nationally representative Supplemental Surveys (SS) conducted in 2000/01, 2004, and 2008[3] by the Zambian Central Statistical Office (CSO), the Ministry of Agriculture and Livestock (MAL), and the Michigan State University Food Security Research Project (FSRP); the Rural Agricultural Livelihoods Survey (RALS) conducted in 2012 by the CSO, the Indaba Agricultural Policy Research Institute (IAPRI), and the FSRP; and the Crop Forecast Survey (CFS) conducted annually by the MAL and CSO for the years 2003–2012. These various data sets each contain information on different aspects of household cropping behavior and crop yields, and we therefore reference them in turn in order to assemble the farm household models. Labor requirements for some crops are taken from a secondary source (Siegel and Alwang, 2005), and we held focus group discussions with local farmers in 2011/2012 to determine the timing of labor inputs. Population weights are used in all relevant analyses. Monetary values are inflated to 2011/2012 values using the consumer price index, and because the Zam-

[2] The Ricardian approach assumes that land values are explained partly by climate, and are determined with consideration of all potential future adaptations (Kurukulasuriya and Mendelsohn, 2008; Seo and Mendelsohn, 2008). This method typically measures the net impact of climate change without revealing what adaptations will be made.

[3] These three survey rounds refer to the 1999/00, 2002/03, and 2006/07 agricultural years. RALS 2012 refers to the 2010/11 agricultural year, while each CFS refers to the season ending in the survey year.