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Methods to assess between-system adaptations to climate change: Dryland wheat systems in the Pacific Northwest United States

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ABSTRACT

In this paper we propose to extend methods for agricultural impact assessment to study the adaptations that agricultural producers are likely to consider in response to climate change – i.e., the use of different combinations of crop or livestock species and associated changes in management. Analysis of these kinds of adaptations, referred to here as "between-system adaptations" – requires estimates of the counterfactual productivity and cost of production for prospective systems that are not observable in the locations where they could be used. We propose two methods that we call simulation matching and propensity score matching. We apply and compare the results of these methods in a study of wheat-based systems in the U.S. Pacific Northwest. We find substantial differences between the two methods, but these differences do not appear to be systematic or associated with characteristics of the systems. We conclude that the method used for estimating the productivity of the new system introduces an element of uncertainty into adaptation analysis, in addition to the other data, model and scenario uncertainties. Further research is warranted to evaluate alternative methods for analysis of between-system adaptations and their associated uncertainties.

1. Introduction

Agricultural production systems must be adapted to ongoing climate change. Despite long-term changes in production technologies, such as crop variety improvement, synthetic fertilizers, large-scale mechanization, chemical pest control, and site-specific management, the most salient feature of major cropping systems remains the combinations of crop and livestock species used by farmers. Predominant cropping system configurations are determined largely by the relative productivity and profitability of the feasible crop and livestock combinations. In major grain producing regions of the United States, the major cropping systems have been relatively stable for many decades, although the boundaries of these systems have shifted in response to technological improvements such as shorter-duration maize varieties, and in response to climate change (Antle et al., 2001; Reilly et al., 2003; Rippke et al., 2016). Thus, with relatively stable soils, and barring any major unanticipated factors such as a new pest or disease outbreak, climate is likely to be the major factor driving cropping system configurations in the foreseeable future, along with long-run trends in economics and policy affecting profitability.

Large-scale modeling studies using aggregated data project changes in land use and production with relatively coarse spatial resolution, and account for the movement of land and labor between agriculture and other sectors of an economy (Nelson et al., 2014; Wiebe et al., 2015), but lack the detail needed to investigate changes in farming system configurations. Field-scale biophysical simulation studies typically include within-system adaptations, such as changes in planting dates and fertilization rates rather than changes in farming system components (Challinor et al., 2014). Econometric studies that estimate statistical relationships between yields or economic outcomes such as land values, revenues or net returns implicitly assume that the most profitable adaptations will be used by farmers, but this type of "reduced form" analysis cannot be used to evaluate specific changes in farming systems (Antle and Stöckle, 2016).

In this paper we develop methods to assess prospective changes in cropping systems in response to climate change and changes in

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socio-economic conditions, using downscaled climate data, detailed farm-level economic data, site-specific farming system simulations, projections of future price and productivity trends, and future socio-economic scenarios. These elements are combined in an economic impact assessment model that simulates both the economic impacts of climate change and the effects of adaptive responses of a heterogeneous population of farm decision makers. Our approach is an extension and elaboration of the Regional Integrated Assessment (RIA) methods developed recently by the Agricultural Model Inter-comparison and Improvement Project (AgMIP) (Antle et al., 2015).

In major dryland cereal producing regions, the most likely climate adaptations will involve changes that producers can make using established knowledge and existing capital and related technologies. Current dryland farming systems utilize crop rotations, tillage systems and crop residue management to maintain soil moisture and soil productivity. In response to climate change, growers can also make adjustments to management practices such as changes in planting dates and fertilization rates. These kinds of changes can be described as *within-system adaptations* because the set of cropping activities is not changed. There is also the possibility of more fundamental changes that may require capital investments as well as changes in the production activities in the system, e.g., adding a new crop species, or shifting from crop to livestock production or to a non-agricultural land use. We refer to such modifications to a production system as *between-system adaptations.*

As we discuss in this paper, modeling these two types of adaptations involves distinct methodological challenges. Antle and Stöckle (2016) show that the analysis of climate adaptations requires the use of models capable of implementing simulation experiments that compare non-adapted and adapted systems under well-defined climate and socio-economic conditions. Utilizing the AgMIP regional integrated assessment methods, within-system changes can be analyzed by utilizing data from an observable system with bio-physical and economic models, to simulate the performance of that system under future conditions. However, the analysis of between-system changes raises an additional analytical challenge, because the prospective adapted system cannot be observed at the locations where it could be used in the future. This problem is analogous to the problem in *ex post* policy impact evaluation of quantifying an unobservable counterfactual (Heckman et al., 1998).

We propose two solutions to this counterfactual problem for climate adaptation analysis that we refer to as the *simulation matching method* and the *propensity score matching method*, and discuss how to implement them. We then compare the results from using these two methods to study cropping system adaptations in the U.S. Pacific Northwest (PNW) wheat systems. These two methods bridge the gap between observable and unobservable counterfactual crop species in two different ways. The simulation matching method uses the observed productivity of a “reference” crop at a study site to infer the productivity of a different crop species at the same location by using the simulated differences in productivity between the two crops under current and future climates. The propensity score matching method uses the observed productivity of a crop at some location, together with its simulated productivity under current and future climates, to predict productivity of the same crop at a site being simulated for the adaptation analysis.

In the second section of this paper, we describe the AgMIP regional integrated assessment methods, explain how we extend those methods to simulate between-system adaptations, and introduce a case study of the wheat-based systems in the Pacific Northwest (PNW). In the third section we summarize our analysis of climate impacts on the PNW dryland wheat systems, and present our analysis of between-system adaptations, including a comparison of the simulation matching method and the propensity score matching method. The final section summarizes our findings and discusses implications for future adaptation research.

2. Materials and methods

2.1. AgMIP regional integrated assessment methods

AgMIP has developed a multi-disciplinary methodology for regional integrated assessment (RIA) of climate change impact, adaptation, mitigation and vulnerability (AgMIP, 2015). The approach is designed to quantify indicators of system performance deemed to be relevant by both stakeholders and scientists. These indicators can include physical outcomes, such as crop yield and production, economic outcomes such as farm income, as well as environmental or social outcomes as appropriate and feasible with available data. Simulation experiments are used to evaluate how system performance responds to climate change, and how that performance responds to system changes intended to adapt to the changed climate, to mitigate greenhouse gas emissions, or both. This multi-scale approach uses results from global modeling studies to generate projections of future prices and crop productivity (both with and without climate change) that can be used as inputs into the regional analysis. To implement the regional assessments, climate data are downscaled, and used to implement crop model simulations. The simulated crop model yield projections are combined with global data and detailed regional economic data to implement regional economic modeling to assess climate impacts and to evaluate the potential benefits of system adaptations.

The foundation of the AgMIP RIA approach is the design of the simulation experiments used in the impact and adaptation analyses. There are many possible simulation experiments that can be carried out (Antle and Stöckle, 2016). Working with various stakeholders, AgMIP has identified “core” research questions for regional integrated assessments. These questions involve climate impacts and the benefits of adaptation under current or near-term future conditions, as well as the longer-term assessment of impact and adaptation using future climate and socio-economic scenarios. The AgMIP RIA methodology is designed to enable research teams, in collaboration with stakeholders, to answer these core questions.

The AgMIP approach begins with the characterization of the existing farming systems. The research team uses this characterization of the current systems to identify the key system components, and the corresponding data and models that will be needed to implement the RIA analysis. For analysis of adaptations, this same process is used to assess how the existing system could be changed. These changes can range from within-system management adaptations such as changes in planting dates, to between-system adaptations such as changes in the rotational system, the introduction of new crop species, or introduction of capital-intensive technologies such as the use of no-till systems or center-pivot irrigation. Also, changes in the farm household’s organization, such as labor allocation between production activities, and between agricultural and non-agricultural activities, can be considered.

The characterization of the existing and prospective farming systems also helps to develop future scenarios by identifying the “exogenous” or “driving” variables that define the bio-physical and socio-economic conditions in which the analysis is conducted. For example, if the analysis is being designed for a future period, it is likely that prices received or paid by the farmers will be different. It is also likely that characteristics of the farm household population will change, such as the farm size distribution. AgMIP has developed systematic methods for creating these future scenarios

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