Dynamic Crop Production Responses to Weather and Yield Realizations with Application in Jordan

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Agricultural production is a fundamental aspect of many societies as a means of producing food and a source of employment and income. However, the variability of production brought on by unforeseeable weather places many farms and communities at risk. This is especially true in developing nations where agricultural households rely on rain-fed agriculture which is inherently dependent on the realizations of rains during the unpredictable rainy season to provide food and/or income. With this dependence of production on rainfall, farmers must adapt and adjust production decisions dynamically throughout the course of the year to mitigate production losses and ensure the availability of food for household consumption.

The study area is in the rain-fed part of the Middle Eastern country of Jordan. In Jordan, water for irrigation has become so scarce that it is no longer used for annual crops (just tree crops such as olives), and farmers rely on seasonal rainfall to produce barley or wheat for large portions of their income, food, and livestock feed. In order to sustain production in the dry and unpredictable climate, farmers must dynamically react to the realizations of weather by varying planting dates, selecting tillage systems, diversifying across crops, adjusting input intensities and harvest and/or grazing timelines.

Each of these production strategies represent choices within a dynamic intra-annual timeline of production for farms, and modelling the subsequent impact of each choice on final outcomes presents relevant results for global research. As areas and nations face increasing water scarcity or political pressure to consume less water in agriculture, understanding how farmers' adaptability to realizations of weather or climate change is important for developing appropriate policy mechanisms. Additionally, recognizing the dynamic path of production choices in response to realizations of weather can help predict when agricultural households are most vulnerable to weather shocks.

Research Methodology

The paper develops a discrete stochastic programming (DSP) model to replicate the dynamic production choices of a farm throughout a calendar year which will be applied to assess technology packages in the dry land farming system of Jordan. In this model, farmers can react dynamically to the realizations of weather and adjust their production behavior over the course of the year. Often production research which models the dynamic strategies of farms focuses on decisions across years or production horizons, as seen in such examples as Rae (1971) or Livingston, Roberts, and Zhang (2014). The model developed here deals with the dynamic choices within a single cropping season where the production incentives and management practices of agricultural households are fully captured. Response farming is a common practice in arid and less developed regions or countries. Therefore, modelling the intra-seasonal weather changes and farmers' dynamic responses to optimize resource use and outputs and to manage risk is especially important in countries such as Jordan.

Modelling the dynamic process of production decisions and outcomes within a stochastic framework presents many difficulties to modelling, given the dependence of both the stochastic process and production decisions on intermediary and final outcomes. The difficulty of modelling the stochastic, dynamic processes of crop growth and responses to management strategies, have likely limited the adoption of dynamic models (Chavas, Kliebenstein, and Crenshaw 1985). A more recent study (Maatman et al., 2002) has attempted to model the stochastic process of production and realization of weather within a DSP framework where only a two-period stochastic process with planting dates and weeding intensity as choices in Burkina Faso are considered. An issue with this study and other previous studies relates to the generalization of periods and outputs into categorically described rainfall events such as "early" or "late". The problem with this type of analysis is that it may misrepresent the reality of production by grouping similar but heterogeneous periods through minimal arbitrarily classified discrete observations.

We propose to use crop simulation tools to generate data from the stochastic process of crop growth and use it to populate a discrete stochastic programming (DSP) model. Using the Agricultural Production Systems Simulator (APSIM), the research builds an extensive set of models and data describing the impact of alternative production choices on final yield outcomes. Instead of arbitrarily classifying stochastic states/outcomes within the model, all outcomes are derived from an empirically tested agronomic simulator which generates the non-Markovian process of dynamic crop production. A DSP model is then used to map the stochastic process of realized weather over the course of the season while using the dependent production responses to optimize outcomes. Using the observed weather and simulated results, the stochastic process is built across time by grouping similar weather and production outcomes by observed threshold levels (such as cumulative rainfall level) for each time period in the model, dynamically across time.

Potential for Generating Discussion

The proposed research presents opportunities for discussion on a variety of methodological and empirical topics, namely methods for modelling the stochastic processes as well as general interest in research on dynamic stochastic production responses and the sustainability of small-holder agricultural households. In modelling the stochastic processes of agricultural production, research has either conjectured (Rae 1971) or approximated (Coulibaly et al. 2014) the stochastic process, all of which require numerous distributional assumptions and more extensive data than is typically available. Using existing crop simulation models provides [in our opinion] a better option for modelling the stochastic process, as rich data sets can be generated for modeling production responses and stochastic realizations of weather. By combining DSP with a crop simulation tool, the results from this approach can offer prescriptive policies relevant for both governments and producers. Additionally, the use of threshold modeling within the stochastic process offers easily interpretable production responses/strategies which can be directly translated to extension service guidelines.

References

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