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Coupling the Tradeoff Analysis Model with a market equilibrium model to analyze economic and environmental outcomes of agricultural production systems

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ABSTRACT

Analysis of the economic and environmental outcomes of agricultural systems requires a bottom-up linkage from the farm to market, as well as a top-down linkage from market to farm. This study develops this two-way linkage between the Tradeoff Analysis Model of agricultural systems and a partial equilibrium market model. The resulting model can determine the effects of technology and policy interventions on the spatial distribution of environmental and economic outcomes at market equilibrium quantities and prices. The approach is demonstrated with a case study of tradeoffs between poverty and nutrient depletion in a semi-subsistence agricultural system (Machakos, Kenya). The results suggest that the linkage of market equilibrium analysis to farm level Integrated Assessment Models can be important in the analysis of agriculture–environment interactions.

1. Introduction

Integrated Assessment Models (IAMs) are used in agricultural research to assess policy impacts on economic and environmental sustainability of agricultural production systems. Assessing the spatial distribution of economic outcomes (e.g., poverty), and environmental impacts (e.g., nutrient depletion) requires the use of spatially explicit data and models. Some farm-level IAMs have been developed to represent the heterogeneity of the physical environment and economic behavior of farmers by integrating site-specific biophysical and economic models. These models typically use spatially-explicit data to model agriculture–environment interactions but treat prices as exogenous (see Goddard et al., 1996; Fleming and Adams, 1997; Brown, 2000; Antle and Capalbo, 2001; Mathur, 2003; Oxley and ApSimon, 2007; Uthes et al., 2010). However, when a policy or a technological change affects many farms, the aggregate responses may impact market equilibrium agricultural prices. Consequently, farm-level IAMs may need to be coupled to market equilibrium models to account for price endogeneity and market interactions in the assessment of agricultural production systems (Kayser, 1999; Verburg and Veldkamp, 2005; Pérez Dominguez et al., 2009).

The goal of this study is to link the Tradeoff Analysis (TOA) Model (Antle et al., 1998; Stoorvogel et al., 2004), to a price-endogenous (partial) market equilibrium (ME) model. The TOA model is an IAM that links site-specific bio-physical process models and economic decision models, and aggregates economic and environmental outcomes to a regional scale, but treats prices as exogenous. The linkage between the TOA model and the ME model allows the effects of site-specific interactions at the farm scale to be aggregated and used to determine market equilibrium. The resulting market equilibrium in turn can be used in the TOA model to determine spatially explicit economic and environmental outcomes. The linkage is illustrated in a case study of the semi-subsistence agricultural production system of Machakos, Kenya. Poverty and sustainability issues are critical in this region where technology or policy interventions are likely to affect the market for maize, a key commodity in Machakos. The case study illustrates the differences in the analysis with and without market equilibrium and the importance of feedbacks in the assessment of tradeoffs between nutrient depletion and poverty in the semi-subsistence agricultural system of Machakos, Kenya. The next section presents the linkage between the TOA model and the ME model. The third section presents the application of the linked models for Machakos, Kenya. The results are discussed in section four followed by general conclusions in the last section.

2. Coupling the TOA and ME model

2.1. The Tradeoff Analysis Model

The TOA model (Fig. 1) incorporates crop models to assess land quality and economic models to simulate land management

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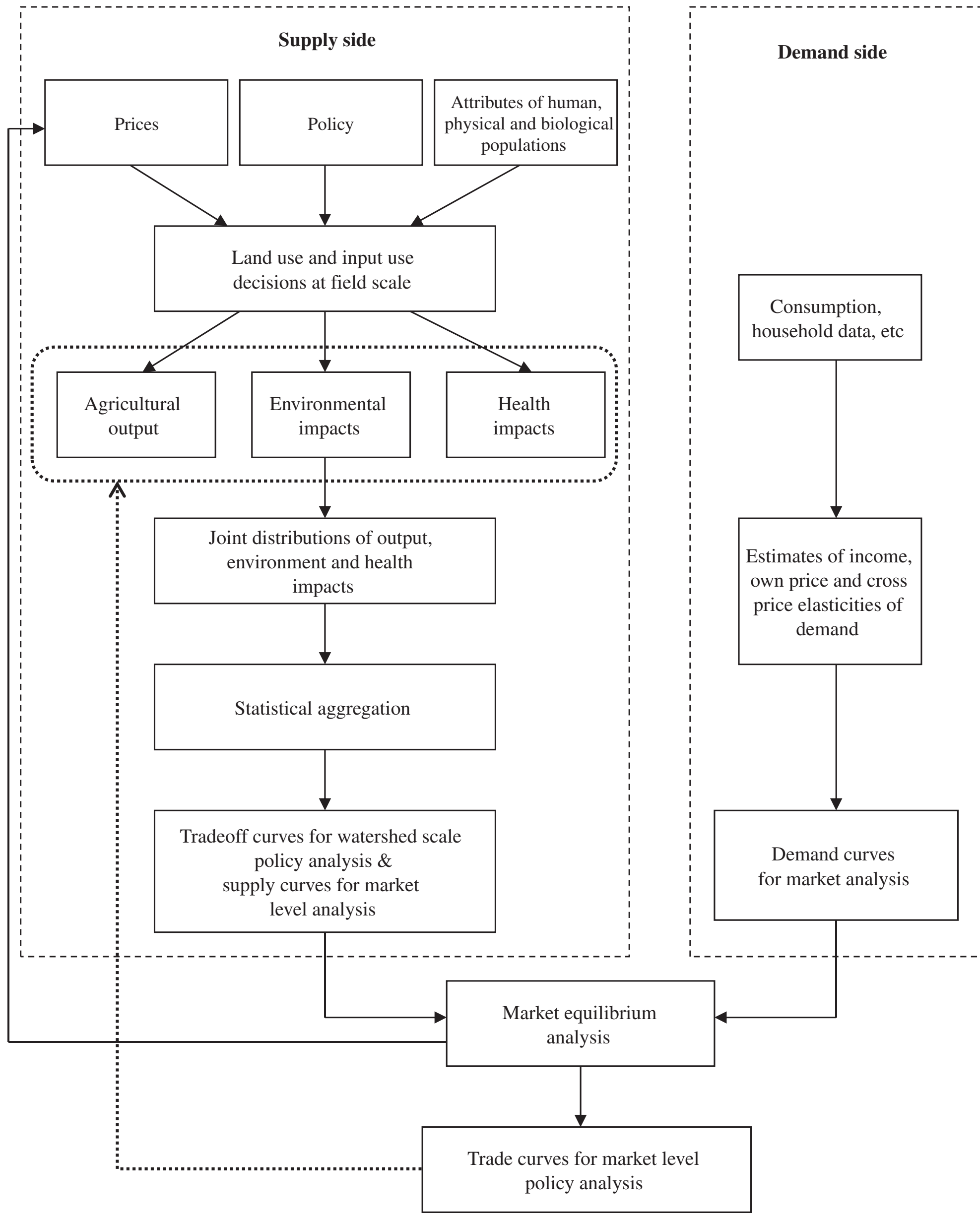

Fig. 1. Conceptual framework for disciplinary integration and policy analysis that include market level linkage (Adapted from Antle et al., 1998).

decisions. Subsequently, those decisions are input in environmental process models to simulate the associated environmental outcomes. These simulations are executed for a statistically representative sample of the farmer population in a region. The site-specific economic and environmental outcomes can then be aggregated to the regional level to create economic and environmental *indicators* of interest to stakeholders. The simulations can be repeated for alternative parameter settings to quantify the inter-relationships (i.e., tradeoffs) among the indicators.

At the farm level, the effects of site-specific soil and climate conditions on productivity potential, or *inherent productivity*, are estimated using crop simulation models. Then an econometric-process model (an empirical econometric production model developed by Antle and Capalbo (2001) and later adapted by Antle et al. (2010a)) simulates site-specific land management decisions using econometric production models (input demand and output supply) that are functions of inherent productivity, prices, farm characteristics, and policy parameters.

Environmental impacts of these management decisions are then simulated using environmental process models. As a result, management decisions and resulting environmental outcomes on each unit of land in production are functions of site-specific environmental conditions, prices, policies, technology and other farm-specific variables. The distributions of these site-specific and farm-specific characteristics in the population generate a joint distribution of economic and environmental outcomes in the population that are functions of the underlying environmental and economic parameters.

With this joint distribution the outcomes can be statistically aggregated into economic and environmental indicators that represent the population. By varying model parameters, such as prices, different environmental and economic outcomes are generated. The aggregate relationships between economic and environmental indicators generated in this way are referred to as *tradeoff curves*. Thus, tradeoff curves represent the supply side of the agricultural system. Here we use the fact that when tradeoff curves are