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A cobweb model of land-use competition between food and bioenergy crops

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ABSTRACT

We present a model of interacting cobweb markets and apply it to land-use competition between food and bioenergy crops. In our model the markets are interlinked on the supply side by the limited availability of land. Therefore, instabilities are transferred between the markets and we find that bioenergy demand affects food price volatility. The agents in the model have heterogeneous production capacities, representing variation in global land quality. When we allow agents to choose price predictor, we find that a more sophisticated (but costly) predictor is concentrated to some key parcels of land, which enables the system to reduce instability significantly. The system can also be brought closer to a stable state by introducing costs for changing production type, but it may then be shifted away from the optimum situation predicted by the corresponding equilibrium model.

1. Introduction

Food price fluctuations have been of interest for centuries among policy makers as well as scientists. One of the first theoretical models to explain agricultural price dynamics was the cobweb model (Ezekiel, 1938). The cobweb model captures an important mechanism in agricultural systems: the time lag between production decisions and realization (sowing and harvest). Due to this time lag the short-run supply is inelastic and suppliers have to base their production decisions on expected future market prices.

Generally, the cobweb model has been limited to the study of individual markets. In an agricultural setting, however, commodities may be interlinked on the supply side, as is pointed out and studied by Dieci and Westerhoff (2009, 2010). Their papers introduce a cobweb system where agents can choose to produce one out of two commodities, thereby

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interlinking the two markets. They find that, when markets are interlinked, policy interventions in one market affect the other market, which may destabilize the whole system.

An area where the findings of Dieci and Westerhoff are highly relevant is the discussion on bioenergy production and food prices. Since agricultural land is a limited production factor, these two markets are inevitably interlinked. During recent years there has been an increased demand for bioenergy (in particular biofuels), mainly due to policies for climate change mitigation and energy security. The increased demand has, in several studies, been claimed to cause rising food prices (Mitchell, 2008; Lipsky, 2008; FAO, 2008; OECD, 2009).

In the policy discussion today, various types of equilibrium modeling approaches are almost always used as a basis for conclusions (Persson, 2014; Fargione et al., 2008; Searchinger et al., 2008; Hertel et al., 2010). There is, though, an increased awareness that models including both dynamic aspects and explicit modeling of mechanisms that reflect the decision processes on the level of individual agents (farmers, firms, etc.), may add important insights and act as a complement to the equilibrium models (Rounsevell et al., 2013; Gouel, 2012).

In this paper we present a model of interlinked cobweb markets for bioenergy and food production with a bottom-up structure of the supply side. The agents in the model are farmers possessing parcels of land with different productivity levels (land qualities). Farmers can only produce one crop at a time and the system inertia is regulated by how large fraction of farmers that is allowed to switch crops each time step. The microeconomic basis of the model builds on a recently presented land-rent equilibrium model, developed for the study of land-use competition between different crop types, see Bryngelsson and Lindgren (2012, 2013).

Central to the dynamics of the cobweb model are price expectations, where the classical assumption is that agents predict present prices to hold, the so-called naive expectation. The expectations feedback is negative: high expected prices lead to high production and thus to a low realized market price, and vice versa. A homogenous population of agents with naive expectations therefore causes prices to oscillate after a shock, even when economic fundamentals subsequently remain constant. However, if most agents use such a simple heuristic, opportunities arise for any “smarter” agent to exploit these foreseeable patterns to improve their own forecasts and increase profits, making such a population unrealistic. In contrast Muth (1961) advanced the hypothesis that agents' expectations essentially are the same as the predictions of the relevant economic theory, without any systematic errors. This would mean that agents have perfect knowledge about the economy and make the best possible use of it, behaving perfectly rationally. Even though this rational expectations hypothesis has become the leading paradigm, it has been criticized for assuming too much knowledge on the part of the agents. In controlled laboratory experiments Hommes et al. (2007) and Hommes (2011) have found that in unstable cobweb-type commodity markets the rational expectations hypothesis is not an accurate description of realized prices. Instead, they find that real agents use different simple heuristics to predict future prices, and that a heterogeneous expectations model is crucial for explaining the market behavior. In this paper we are interested in how increased information may influence system stability. Therefore we consider, in the style of Brock and Hommes (1997) only two types of predictor functions: “naive” and “rational”, the latter having perfect information about next year's prices.

In the basic setting we have a controllable mix of the two predictors. In an extension of the model, we include adaptive agents that are allowed to choose between the more costly rational predictor and the free naive one. The choice is based on the performances of the predictors among agents having the same production capacity (i.e., among agents owning land of the same quality). Combining heterogeneous price expectations with heterogeneous production factors has not been done before in a cobweb model, and it allows us to study on which land quality the rational predictor is successful. We also investigate the effect of noise in supply and how it influences the presence of rational agents and stability. Another model extension investigates a new type of inertia: a cost for switching crops.

The contribution of this paper is twofold. We extend the research on interacting cobweb markets that was initiated by Dieci and Westerhoff (2009, 2010), by applying a model of such a system to an important question in the current land-use debate. We also introduce a new combination of heterogeneity that includes both production capabilities and price expectations to the cobweb model.

2. Model description

The framework for our model is a simple, conceptual agricultural land-use system, representing the production on all agricultural land worldwide. In this system agents are farmers owning their land, and they are assumed to make decisions solely based on profit maximization. Production is conceptualized by n generic crop types that are sold on a global market where prices are endogenously set. The options for land use are thus: producing one out of the n generic crop types, or leaving the land idle.

The landscape on which the model operates is defined by agricultural land of varying relative productivity, $Y(a) \in [0, 1]$, but with no explicit geographic representation. In our representation of land, we arrange land parcels in increasing productivity order, from the least productive, $Y=0$, to the most productive, $Y=1$. Hence, $Y(a)$ represents the relative production level when a total area of a Gha of less productive land has already been used. Here we assume that there is a linear form of the relative productivity, $Y(a) = a/A$, which is an approximation derived from real world estimates found in Fisher et al. (2002). In the expression for $Y(a)$, A is the total agricultural land available, which is currently about 5 Gha [1 Giga hectare $= 10^7$ km^2]. Land that is currently not used for agriculture, such as forest areas, is not included in the model.