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A behavioral cobweb-like commodity market model with heterogeneous speculators

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ABSTRACT

According to empirical studies, speculators place significant orders in commodity markets and may cause bubbles and crashes. This paper develops a cobweb-like commodity market model that takes into account the behavior of technical and fundamental speculators. We show that interactions between consumers, producers and heterogeneous speculators may produce price dynamics which mimics the cyclical price motion of actual commodity markets, i.e., irregular switches between bullish and bearish price developments. Moreover, we find that the impact of speculators on price dynamics is non-trivial: depending on the market structure, speculative transactions may either be beneficial or harmful for market stability.

1. Introduction

A key characteristic of commodity price dynamics is their strong cyclical behavior. Cashin et al. (2002), who examine the price action of 36 commodities in the period from 1957 to 1999, report that the average price fall across all commodities was 46% during slumps, while the average price rise across all commodities was 42% during booms. Individual price series are, of course, even more volatile: The price for coconut oil dropped by around 88% between June 1984 and August 1986 and the price of coffee arabica increased by around 84% from April 1975 to April 1977. Further empirical evidence of commodity price fluctuations is provided by Borenzstein et al. (1994) and Deaton (1999). Alterations between bull and bear markets have important implications for many developing countries dependent on commodity exports. Dramatic price changes may cause severe fluctuations in earnings from commodity exports. A thorough understanding of commodity price dynamics is thus of great significance, especially for policy makers who plan to conduct counter-cyclical stabilization policies (Newbery and Stiglitz, 1981).

Several theories have been proposed which give us valuable insight into the dynamics of commodity prices. Our approach is related to cobweb models (e.g. Coase and Fowler, 1937; Ezekiel, 1938 or Nerlove, 1958) which describe the price dynamics in a market of a non-storable good that takes one time unit to produce. As a result, suppliers must form price expectations one period ahead. Such a view is not unrealistic. Consider, for instance, the cultivation of crops. The growing season guarantees a finite lag between the time the production decision is made and the time the crop is ready for sale. The decision about how much should be produced is based on current and past experience. Remember that classical linear cobweb models with naive expectations are able to reproduce oscillatory price movements with decreasing amplitude.

The cobweb approach has been extended in several directions. Exploiting nonlinearities in demand and supply, Chiarella (1988), Day (1994) and Hommes (1994, 1998) analytically show the possibility of chaotic price dynamics for different adaptive expectation schemes of the producers. In Brock and Hommes (1997), the demand and supply curves are linear, but producers switch between different forecasting strategies. Depending on publicly available fitness measures, producers opt either for naive or (costly) rational expectations. The choice is rational in the sense that predictors with a high level of fitness are preferred. The model not only yields complex price dynamics but suggests that irregular dynamics may be part of a fully rational notion of equilibrium.[1] The study of cobweb markets is still an active field of research, see, for instance, the recent contributions by Chiarella and He (2003), Chiarella et al. (2006) and Dieci and Westerhoff (2009).

This paper seeks to offer a new perspective of commodity price fluctuations by adding heterogeneous speculators, i.e. interacting chartists and fundamentalists, to the traditional cobweb framework. In fact, there exists widespread evidence that private and professional speculators apply both technical and fundamental analysis to predict commodity price movements. For instance, Smidt (1965) reports that the majority of the speculators rely at least partially on price charts to

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[1] This approach receives, for instance, empirical support from Baak (1999) who estimates the fraction of boundedly rational farmers in the U.S. cattle market.

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render trading decisions in commodity markets. Similar results are reported in questionnaire studies of Draper (1985) and Canoles et al. (1998). In addition, Sanders et al. (2000) find strong evidence of positive feedback trading in several commodity markets and Weiner (2002) detects herding behavior in the petroleum market. Overall, these studies indicate that chart and fundamental speculation is a major factor for price variation in commodity markets.

In line with the early cobweb literature, we construct a behavioral cobweb-like model with a supply response lag. The demand and supply schedules of the consumers and producers are linear and the producers have naive expectations. The market is cleared by the price sensitive demand of the consumers. But the supply available to consumers also depends on the trading decisions of the speculators, i.e. their excess selling (buying) increases (decreases) the supply.[2] The speculators apply both technical and fundamental methods to predict prices. While technical analysis extrapolates past price trends into the future, fundamental analysis assumes that prices converge towards their fundamental values. The speculators are boundedly rational in the sense that they tend to use forecast rules with a high level of fitness. Note that the speculators' switching between technical and fundamental rules introduces a non-linearity into the model.

We are interested in how speculators may influence the evolution of commodity prices.[3] Overall, our model is able to generate price dynamics which mimic the cyclical swings of commodity prices quite well. We derive the following results. Suppose that the cobweb market is stable without speculators. Then a pitchfork bifurcation, followed by a period doubling bifurcation, may emerge as the total number of speculators increases. Further simulation analysis reveals that after many period doubling bifurcations the dynamics becomes chaotic. For certain parameter values, we observe the emergence of bull and bear markets, as well as irregular price fluctuations between bull and bear markets.

However, if the demand and supply schedules of the consumers and producers violate the stability condition, we show that the presence of a critical mass of speculators may stabilize the market. Instead of a price explosion, the price may settle down on a complicated attractor, a limit cycle or even a fixed point. This finding is quite remarkable: The common suggestion to crowd out speculators may not always be beneficial to market stability. In fact, complex interactions between technical and fundamental speculators may prevent unstable price trajectories.

The remainder of this paper is organized as follows. Section 2 develops a behavioral cobweb-like commodity market model with heterogeneous boundedly rational speculators. In Section 3, we present our analytical results and in Section 4, we numerically illustrate the dynamics. The last section offers some conclusions and points out some extensions.

2. A cobweb-like commodity market model with consumers, producers and speculators

2.1. The behavior of consumers and producers

Remember that traditional versions of the cobweb model describe a dynamic price adjustment process on a competitive market for a single non-storable good with a supply response lag. Market clearing occurs in every period

$$D_t = S_t, \tag{1}$$

where D and S denote demand and supply, respectively. To keep the model as simple as possible, we focus on linear demand and supply curves. Consumer demand depends negatively upon the current market price P

$$D_t = \frac{a - P_t}{b}. \tag{2}$$

The output decision of the producers depends on their price expectations. We assume that producers have naive expectations (i.e. $E[P_t] = P_{t-1}$), which entail a so-called supply response lag. Hence, the supply of the producers in period t is

$$S_t^P = \frac{E[P_t] - c}{d} = \frac{P_{t-1} - c}{d}. \tag{3}$$

As usual, we assume that $a, b, d > 0$, $c \geq 0$ and $a/b > c/d$.

In the absence of speculators ($S_t = S_t^P$), the law of motion of the price, obtained by combining Eqs. (1)–(3), is a one-dimensional linear map

$$P_t = \frac{ad + bc}{d} - \frac{b}{d} P_{t-1}, \tag{4}$$

which has a unique fixed point at

$$F = \frac{ad + bc}{b + d}. \tag{5}$$

We regard the fixed point F as the fundamental value of the market. The law of motion may be simplified by rewriting Eq. (4) in terms of deviations from the fundamental value. Defining $X_t = P_t - F$, Eq. (4) becomes

$$X_t = -\frac{b}{d} X_{t-1}. \tag{6}$$

As is well known, market stability requires

$$b / d < 1. \tag{7}$$

If Eq. (7) holds, P is attracted by F, and X converges towards 0.[4] Furthermore, since the parameters b and d are positive, the price adjustment is oscillatory.

2.2. The behavior of speculators

Our perspective is that producers such as farmers are mainly concerned with the production process. At the commodity exchange, where commodities are usually traded, many additional speculators are active. As revealed by empirical studies, private and professional speculators use technical and fundamental trading strategies to determine their investment decisions (Smidt, 1965; Draper, 1985; Canoles et al., 1998; Sanders et al., 2000). Speculators apparently have a marked influence on the evolution of commodity prices.

Interactions between chartists and fundamentalists have already been explored in detail in several stock market models. So-called fundamentalists are agents who believe in mean reversion, i.e. they expect prices to return towards fundamentals. Agents using technical analysis, so-called chartists, bet on the persistence of past price trends. Models by Day and Huang (1990), Huang and Day (1993), de Grauwe et al. (1993), Brock and Hommes (1998), Lux and Marchesi (2000), Chiarella and He (2001) and Chiarella et al. (2002) demonstrate that the behavior of heterogeneous speculators may endogenously create complex financial market dynamics.

[2] Contrary to the classical cobweb model, we thus assume that the commodity is storable. Note that this is indeed the case for most commodities.

[3] The argument that speculators may be destabilizing has a long history, see e.g. Baumol (1957).

[4] Note that the parameters a and c just shift the demand and supply curves vertically upwards or downwards. Hence, the price and its fundamental value both increase in a and c, yet X – the law of motion – is independent of a and c. Without loss of generality one may assume that a and c take values such that prices and production quantities are always positive.